AD-A268 083

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

2. REPORT DATE 1993	3. REPORT TYPE AND DATES COVERED Final Report 11/15/90 - 3/31/93
4. TITLE AND SUBTITLE On Predicting the Person-in-Water Drift for Search and Rescue	5. FUNDING NUMBERS Grant No. N00014-91-J-1420
6. AUTHOR(S) Tsung-chow Su	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Center for Applied Stochastics Research Florida Atlantic University 500 NW 20th St. Boca Raton, FL 33431-0991	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research 800 North Quincy Street Arlington, Virginia 22217-5000	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unlimited	12b.

13. ABSTRACT (*Maximum 200 words*)

Search and rescue of persons in distress on the high seas requires the capability to accurately predict the position of the survivors. The current approaches on drift prediction are based on an empirical correlation between wind speed and person motion from limited field data. There is also no drift data available for person wearing survival suit. Consequently, there is not sufficient data for accurate prediction and thus have complicated the search and rescue operation. A study is being undertaken at Florida Atlantic University in which the essential effects of environmental forces and person-in-water characteristics will be properly accounted for. The study is intended to provide a theoretical framework and a better understanding of the dynamics of drift, and will thus lead to a reliable model of drift prediction and improved efficiency in search and rescue mission. The study consists of the following components: The development of a mathematical model for the drift prediction problem, laboratory studies of drift forces and field experiments to calibrate the mathematical models and to verify the model prediction.

14. SUBJECT TERMS Leeway, drift, person-in-water, search and rescue			15. NUMBER OF PAGES 83
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

Final Report

ON PREDICTING THE PERSON-IN-WATER DRIFT FOR SEARCH AND RESCUE

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1993

Grant No. N00014-91-J-1420

Prepared For
Office of Naval Research, U.S. Department of Navy

ABSTRACT

Search and rescue of persons in distress on the high seas requires the capability to accurately predict the position of the survivors. The vital importance of search and rescue calls for continuing effort to improve this capability to the extent developing technologies will support. The current approaches on drift prediction are based on an empirical correlation between wind speed and person motion from limited field data. There is also no drift data available for person wearing survival suit. Consequently, there is not sufficient data for accurate prediction and thus have complicated the search and rescue operation.

A study is being undertaken at Florida Atlantic University in which the essential effects of environmental forces and person-in-water characteristics will be properly accounted for. The study is intended to provide a theoretical framework and a better understanding of the dynamics of drift, and will thus lead to a reliable model of drift prediction and improved efficiency in search and rescue mission.

The study consists of the following components: The development of a mathematical model for the drift prediction problem, laboratory studies of drift forces and field experiments to calibrate the mathematical models and to verify the model prediction.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Mr. Quincy Robe, U.S. Coast Guard R&D Center for his guidance throughout the project. Sincere thanks are due to his students L. Wei and H. Khuc for conducting laboratory experiments.

The field test was carried out in Long Key Florida with the assistance of Keys Marine Laboratory. The author is indebted to the help of the laboratory's personnel, especially Mr. John Swanson, the Facilities Service Manager. Several graduate assistants including Messrs. Bob Milo, Q.C. Li, W. Li, H. Khuc, P. Reddy, and D. Duan, and undergraduate assistants, Messrs. G. Janssen II, P. Jean, L. Martin, M. Jaen and C. Robaina, Jr., contributed to the field test. Without their contributions, it would not have been possible to attain the objectives of the project. The author is indebted to the outstanding performance of this field team, especially Mr. Bob Milo, the field coordinator.

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CHAPTER 1

INTRODUCTION

The sea surface is a complex and dynamic environment. Many factors affect the drift of life rafts and disabled boats so that successful search-and-rescue missions depend on human intelligence, on the intuition and insight gained from many years at sea, and on the engineering tools developed for that task. With the interest in providing better data for the computation of drift in search planning, numerous efforts have been made to determine the effects of the surface current on a drifting object (Tomczak, 1964; James, 1966; Meyer, et al, 1969) and the effect of the wind on a drifting object, (Pingree, 1944; Chapline, 1960; Hufford and Broida, 1974 Morgan, et al 1977; Morgan 1975, Scobie and Thompson, 1979; Osmer, Edwards and Breitler, 1982; Nash and Willcox 1985). Leeway is defined as the movement of an object through the water caused by wind acting on the object. Previous studies on leeway prediction were reviewed in the reports by Hufford and Broida (1974) and Nash and Willcox (1985). Table 1-1 summarized the current leeway information available in the National Search and Rescue Manual.

While extensive field tests were conducted over decades to obtain these empirical relationships between leeway and wind speed, these relationships still remain to be of limited validity. As was pointed out by Osmer, Edwards and Breitler (1982), these problems associated with leeway predictions are:

1. each type of craft displays different leeway characteristics;

2. a complex relationship exists between leeway motion and wind speed for wind speeds less than 5 knots;

3. the adequacy of the present leeway factors of 0.03 to 0.07 remains unknown; and

4. the leeway angle is difficult to predict.

A mathematical model was developed by Su (1986) to predict the boat and raft's drift for given environmental conditions. The model predictions and field test measurements resulted in excellent agreement. The model was later simplified for operational use of search and rescue of disabled boats and rafts.

However, for other types of search target, hydrodynamic/aerodynamic characteristics are expected to vary. Laboratory testing is needed to provide force coefficients for the input of the mathematical model. The model developed will need to be verified in a field test to prove it valid. In response to the operational need, the present study will investigate the drift character of person-in-water in survival suit. The survival suits are designed to retain a person's body heat, and has an inflatable pillow behind the hood to keep a person's head above water. The person-in-suit will assume a horizontal position on water surface rather than upright position in water. Their drift characteristics, wind loading and current drag are much different from the person not in suit. Unless their drift characteristics are known and the drifting person can be found timely, the suits only prolong death.

A study was then undertaken at Florida Atlantic University (FAU) to model the person-in-water drift for a given environmental condition. In the FAU model, the essential effects of environmental forces and floating characteristics were properly accounted for through analysis rather than through correlation. The study is intended to provide a theoretical framework and a better understanding of the dynamics of drift and will thus lead to a reliable model of drift prediction and improved efficiency in search and rescue missions.

The study consists of two major components. One deals with the development of a mathematical model and determines the force coefficient through laboratory tests for the drift prediction problem. The other deal with an extensive field test to collect accurate field data. Post-experiment simulations were run using the collected environmental data as an input to the developed model. Systematic comparison of the measured drifts with the theoretical prediction for nineteen drift cases furthered the model development. A new drifter for current measurement was developed and was used in field study. Eventually, all of the essential effects, except those associated with stormy weather, were accounted for. The resulting drift prediction model is accurate and efficient. With its accuracy staying within the field test error and its efficiency allowing practical real-time simulations, a reliable, working model had then been developed.

The study was undertaken according to the ONR Grant N00014-91-J-1420. In terms of scientific merit, the study will provide a better understanding of the dynamic processes of floating objects in the ocean. This will improve the basis for reliable, accurate and timely drift prediction. It would also provide useful information for search and rescue planning. The present report covers the work carried out in the study.

TABLE 1.1 CURRENT LEEWAY INFORMATION AVAILABLE IN SAR MANUAL

(From Nash and Willcox, 1985)

TYPE OF CRAFT	WIND SPEED*	LEEWAY SPEED*,†	LEEWAY ANGLE (deg)	REFERENCE
Light-displacement cabin cruisers (no drogue) Outboards (no drogue) Rafts without canopies/ballast system (no drogue) Rafts with canopies and ballast buckets	0-5 (0-2.6) 5-40 (2.6-20.6)	0.078U 0.07U + 0.04 (0.07U + 0.02)	±35	Hufford and Broida (1974)
Light-displacement cabin cruisers (with drogue) Outboards (with drogue) Rafts without canopies or ballast system (with drogue) Canopied raft with deep-draft ballast system	0-5 (0-2.6) 5-40 (2.6-20.6)	0.026U 0.05U - 0.12 (0.05U - 0.06)	±35	Hufford and Broida (1974) Scobie and Thompson (1979)
Large cabin cruisers	0-40 (0-20.6)	0.05U	±60	Chapline (1960)
Medium-displacements sailboats Fishing boats (e.g., trawlers, trollers, tuna boats)	0-40	0.04U	±60	Chapline (1960)
Heavy-displacement, deep-draft sailing vessels	0-40	0.03U	±45	Chapline (1960)
Surfboards	0-40	0.02U	±35	Chapline (1960)

NOTE: Leeway speed and angle information available in the National Search and Rescue Manual is listed with the most likely original source of the equations.

* Values and equations in parentheses are for meters/second (m/s), if different. All others are in knots.

† U is wind speed.

CHAPTER 2

ANALYSIS

2.1 Elementary Leeway Formulas

A simplified analysis is presented which is consistent with the development of the linear leeway formula currently used for search and rescue applications. A more general approach may be developed. However, its application may be limited by other factors of uncertainty which may occur in search and rescue situations.

Forces exerted on a solid body when fluid flows by it or when it moves through a fluid are termed the drag and the lift, depending on whether the force is parallel to the motion or at right angles to it. The general expression of the drag force, F_D is

$$F_D = C_D \frac{1}{2} \rho V|V|$$

This equation refers to the drag force exerted on the body having characteristic area A, characteristic length L, moves through a fluid of density ρ and kinematic viscosity ν with a relative speed V. C_D in the above expression is a function of body geometry and the Reynolds number N_R which is VL/ν.

Drag cceefficient as a function of body geometry and Reynolds number is given in the Figure 2.1. Analytical means of obtaining drag coefficient are limited. Our practical knowledge on determining C_D is mainly empirical.

Consider the simple case of a floating object, with its "sail area" A_1 exposed to a steady uniform wind of velocity U_1, and its "keel plane area" A_2 facing a steady current with velocity U_2 as shown in Figure 2.2. The "sail area" is the total broadside area of the person which extends above the waterline, and the "keel plane area" is the broadside area extending below the waterline.

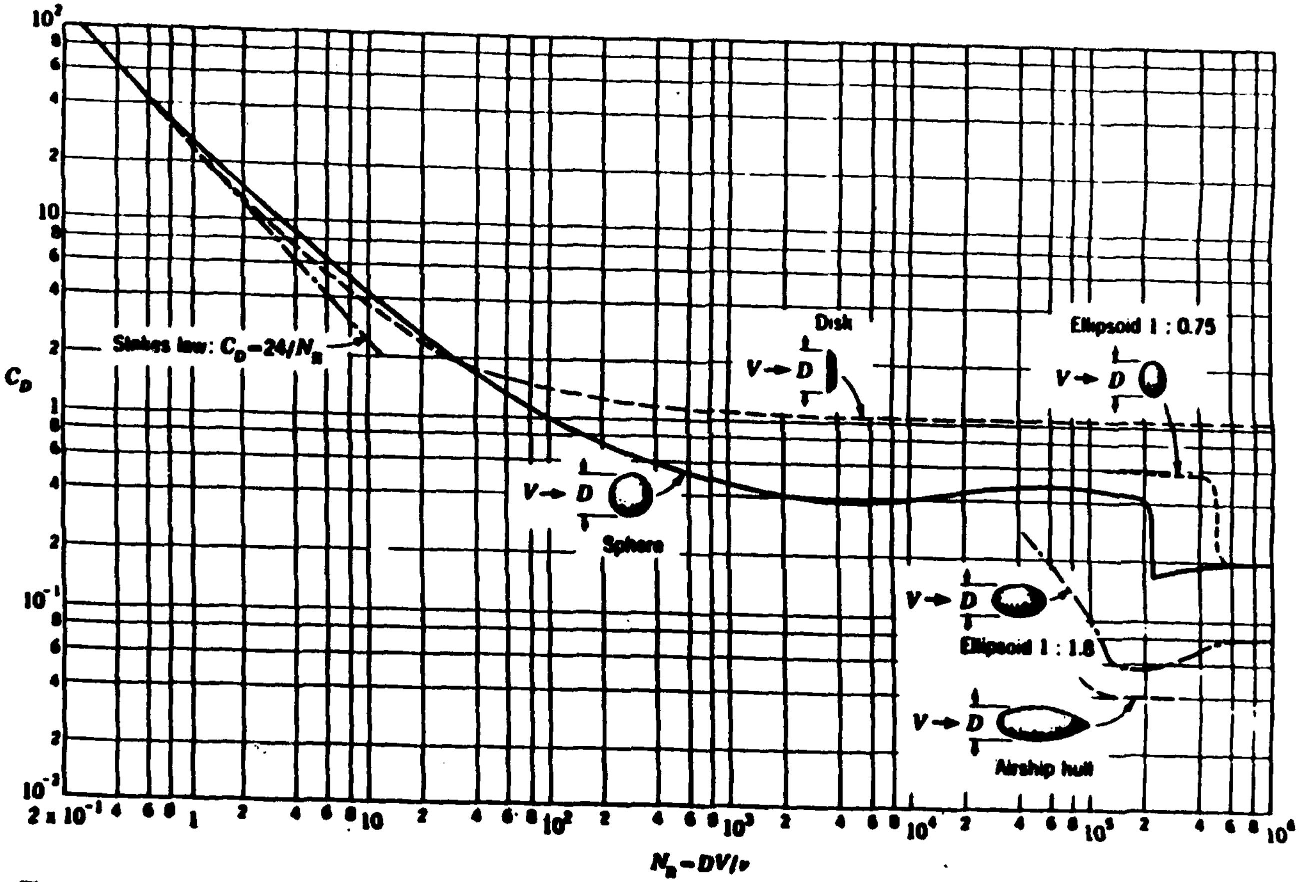

Figure 10.18. Drag coefficient for bodies of revolution. (Adapted from L. Prandtl, "Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen," p. 29, R. Oldenbourg, Munich and Berlin, 1923; and F. Eisner, "Das Widerstandsproblem," *Proc. 3d Internatn. Congr. Appl. Mech.*, p. 32, 1930.)

Figure 2.1 DRAG COEFFICIENT

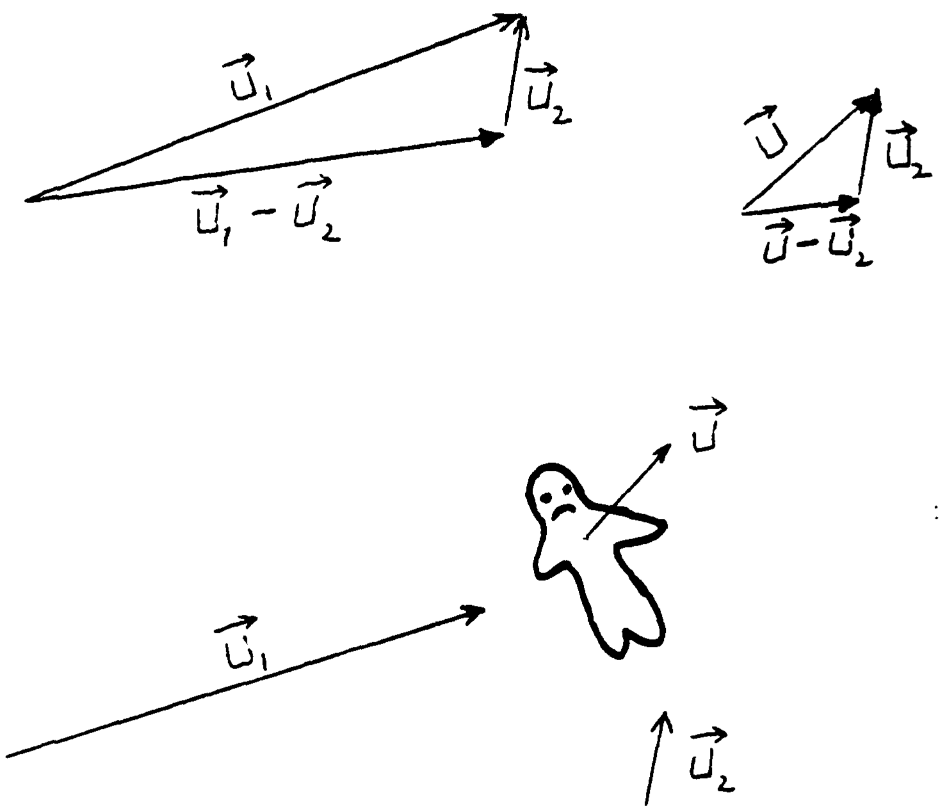

Figure 2.2 Person-in-water Drift in Wind and Current

As the result of wind forcing and current retardation, a steady person-in-water drift velocity U is achieved. The force balance can be expressed as follows

$$\frac{1}{2} C_1\rho_1A_1 (U_1 - U) |U_1 - U| = \frac{1}{2} C_2\rho_2A_2 (U_1 - U) |U - U_2| \quad (2.1)$$

Thereafter, the subscript "1" refers to the air medium while the subscript "2" refers to the sea water medium. Assuming both Reynolds Number N_{R_1} and N_{R_2} to be large, C_1 and C_2 are constant. The drift velocity U can be solved easily from equation (2.1) as

$$U = \frac{\lambda}{1 + \lambda} U_1 + \frac{1}{1 + \lambda} U_2 \quad (2.2)$$

in which $\lambda = \lambda_1/\lambda_2$ with $\lambda_1^2 = C_1\rho_1A_1$ and $\lambda_2^2 = C_2\rho_2A_2$.

The leeway is defined as the movement of an object through the water caused by wind acting on the object. The leeway velocity U_L can be obtained by subtracting current velocity from the drift velocity, i.e.

$$U_L = U - U_2 = \left(\frac{\lambda}{1 + \lambda} \right) U_1 - \left(\frac{\lambda}{1 + \lambda} \right) U_2 = \frac{\lambda}{1 + \lambda} (U_1 - U_2) \quad (2.3)$$

2.3 Solution Significance

We note the following:

(1) The expression is in agreement with the important finding of Chapline (1960) that the leeway speed of the small craft without a drogue is directly proportional to the wind velocity (at least for moderate to fresh winds). For a person-in-water of 2 ft. shoulder width or larger, with a wind speed of 5 knots (8.44 ft/s) or higher, the standard atmosphere air kinematic viscosity of 1.57 x 10^{-4} ft^2/s leads to the Reynolds No. $N_{R_1} \sim 0(10^5)$. The corresponding N_{R_2} is expected to remain of the same order of magnitude. This is because while current speed is typically one order of magnitude smaller than the wind speed, the water's kinematic viscosity is also one order of magnitude smaller than

that of air. Thus the applicability of equation (2.3) for person-in-water drift for wind speed of 5 knots or above is justified.

(2) There are circumstances where N_{R_1} and/or N_{R_2} are not large enough to justify full turbulence behavior of constants C_1 and C_2. This may happen if the wind is of 5 knots or less. For a more general treatment, the following functional dependence may be assumed

$$C_1 = C_1' |U_1 - U|^{-n_1} \tag{2.4}$$

with a similar expression for C_2. For full turbulent conditions $n_1 = 0$, for the case of laminar boundary layer flow, $n_1 = 1/2$ and as $N_R << 1$, $n_1 \rightarrow 1$, (Daugherty and Franzini, 1977). Consider again the steady drift and, for simplicity, assuming co-flowing wind and current, the force balance leads to

$$\frac{1}{2} \lambda_1'^2 (U_1 - U)^{2-n_1} = \frac{1}{2} \lambda_2'^2 (U_2 - U)^{2-n_2}$$

or

$$\lambda' (U_1 - U)^{1+n'} = U - U_2 \tag{2.5}$$

In which $\lambda_1'^2 = \rho_1 A_1 C_1'$, $\lambda_2'^2 = \rho_2 A_2 C_2'$

$$\text{While} \qquad \lambda' = (\lambda_1'/\lambda_2')^{\frac{2}{2-n_2}} \quad \text{and } n' = \frac{n_2 - n_1}{2 - n_2} \tag{2.6}$$

Following the usual definition of leeway, letting $U = U_2 + U_L$ equation (2.5) can then be written as

$$U_L = \lambda' [U_1 - (U_2 + U_L)]^{1+n'}$$

As the wind speed is typically much larger than the person drift $(U_2 + U_L)$ the following expansion is valid

$$U_L = \lambda' U_1^{1\;n'} \left[1 - \frac{U_2 + U_L}{U_1} \right]^{1\;n'}$$

$$\doteq \lambda' U_1^{1\;n'} \left[1 - (1+n') \frac{U_2 + U_L}{U_1} \right]$$

Therefore

$$U_L = \left[\frac{\lambda'}{1+\lambda'(1+n')U_1^{n'}} \right] U_1^{1\;n'} - \left[\frac{\lambda'(1+n')\,U_1^{n'}}{1+\lambda'(1+n')U_1^{n'}} \right] U_2 \tag{2.7}$$

Aside from the transition range, N_{R_1} and N_{R_2} are generally of the same order, $n_1 = n_2$. Therefore $n' = 0$. Hence, equation (2.7) can be reduced to

$$U_L = \left(\frac{\lambda'}{1+\lambda'} \right) U_1 - \left(\frac{\lambda'}{1+\lambda'} \right) U_2 = \left(\frac{\lambda'}{1+\lambda'} \right) (U_1 - U_2) \tag{2.8}$$

where λ' is defined according to (2.6). For complete turbulent flow or high Reynolds Number flow as typically occur in moderate to fresh wind, $n_2 = 0$ and as discussed before

$$\lambda' = \left(\frac{\rho_1 A_1}{\rho_2 A_2} \right)^{1/2} \sim 3.5 \times 10^{2} \left(\frac{A_1}{A_2} \right)^{1/2} \tag{2.9}$$

For laminar flow with moderate N_R, $n_2 = 1/2$ and

$$\lambda' = \left(\frac{\rho_1 A_1}{\rho_2 A_2} \right)^{2/3} \sim 1.1 \times 10^{2} \left(\frac{A_1}{A_2} \right)^{2/3} \tag{2.10}$$

For very low Reynolds Number flow, $n_2 = 1$ and

$$\lambda' = \left(\frac{\rho_1 A_1}{\rho_2 A_2} \right) - 1.2 \times 10^{-3} \left(\frac{A_1}{A_2} \right) \qquad (2.11)$$

We note that the basic solution (2.3) can be generalized to deal with low wind speed case, provided that the leeway factor λ' is used instead of λ.

One may also expect that for person-in-water wearing survival suit, flow separation shall occur at fixed corners, the sudden drop of drag in transition from laminar flow to turbulent may not occur.

2.3 Wave Effect

Hufford and Broida (1974) reported that small craft leeway appears to increase up to about 15% with increasing sea state. However, the relationship has not been quantitatively established. Included in this section is a simple derivation to account for the wave effect on drift and to assess its significance.

The wave drift force can be expressed by

$$F = \frac{1}{2}\rho_2 g\, L\, C_{2w}\, a^2 \tag{2.12}$$

with g representing acceleration due to gravity, a, the wave amplitude (which is one-half of the wave height) and C_{2w} denoting the wave drift coefficient in a regular wave which is a function of the frequency of the incoming waves and may reach a value of order of one in some cases. Including the wave drift force in the force balance equation of (2.1), and for assuming the wave, wind and current are along the same direction, we obtained

$$\frac{1}{2}\rho_1(U_1 - U)^2 A_1C_1 - \frac{1}{2}\rho_2(U - U_2)^2 A_2C_2 + \frac{1}{2}\rho_2\, gLC_{2w}\, a^2 = 0 \tag{2.13}$$

This equation can be solved to yield

$$U = U_o - \frac{U_o-U_2}{1-\lambda} + \sqrt{\left(\frac{U_o-U_2}{1-\lambda}\right)^2 + \frac{\alpha}{1-\lambda^2}} \tag{2.14}$$

where U_o is the solution of (2.14) when a = o, thus

$$U_o = \frac{\lambda}{1+\lambda}U_1 + \frac{1}{1+\lambda\, U_2}U_2$$

and (2.15)

$$\alpha = \frac{gLC_{2w}a^2}{A_2\, C_2}$$

For large α, wave effect is considerable as indicated in equation (2.14). While for small α assuming $\alpha << |U_o - U_2|$,, equation (2.14) can be reduced to yield

$$U = U_o + \frac{1}{2} \frac{\alpha}{(1+\lambda)(U_o - U_1)}$$

so that

$$U_L = \frac{\lambda}{1+\lambda}(U_1 - U_2) + \frac{1}{2} \frac{\alpha}{\lambda (U_1 - U_2)} \qquad \textbf{(2.16)}$$

For zero α (2.16) reduces to (2.3), as expected. From (2.16) it is obvious that the wave effect on leeway is negligible if

$$\left[\frac{1}{2} \frac{\alpha}{\lambda(U_1 - U_2)}\right] \div \left[\frac{\lambda}{1+\lambda}(U_1 - U_2\right] << 1 \qquad \textbf{(2.17)}$$

i.e.

$$\frac{1}{2}\left(\frac{1+\lambda}{\lambda^2}\right)\frac{1}{(U_1 - U_2)^2} \frac{gLC_{2w}a^2}{A_2 C_2} << 1$$

Since $\lambda<<1$, $U_1>>U_2$ and $A_2 \sim L^2$, for wave drift to be neglected

$$\frac{a}{L} << \lambda \left(\frac{2 C_2}{C_{2w}}\right)^{\frac{1}{2}} \frac{|U_1 - U_2|}{\sqrt{gL}} \qquad \textbf{(2.18)}$$

This condition may not generally be satisfied. It is therefore concluded that wave drift needs to be included in the drift prediction for stormy weather search.

2.4. Implementation

In general, the boat will turn its broadside into the wind. The field observation indicated that this is also true for a person-in-water wearing survival suit. The fluid dynamics explanation is as follows. As shown in Figure 2.3, (a), a boat is exposed to wind with its broadside turned to the wind, relative current drag counteracts and an equilibrium condition results. The "S" in the figure denotes the stagnation point at which point velocity is zero and the maximum pressure occurs. The figure 2.3(b) shows a small perturbation of the previous condition. The stream pattern was altered and the location of maximum pressure shifted, which tends to bring the boat back with its broadside turned into the wind again.

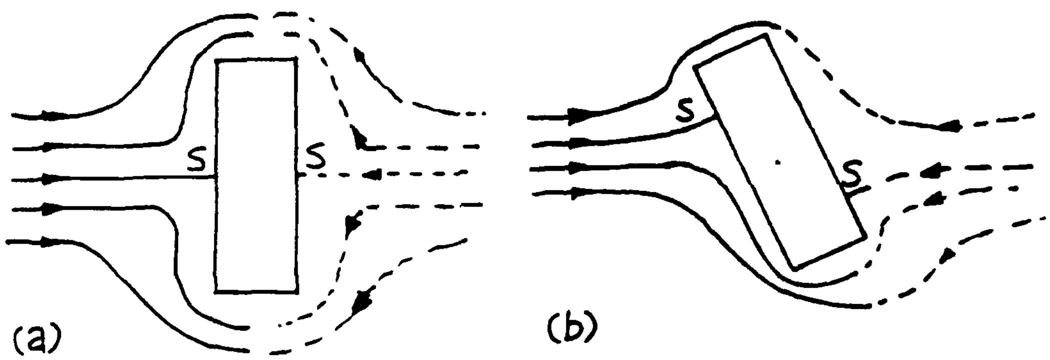

Figure 2.3 Flow Pattern and Fluid Forcing

_____________ wind stream; ------- current

Figure 2.4 (a) shows a condition of ship with its bow facing the wind.

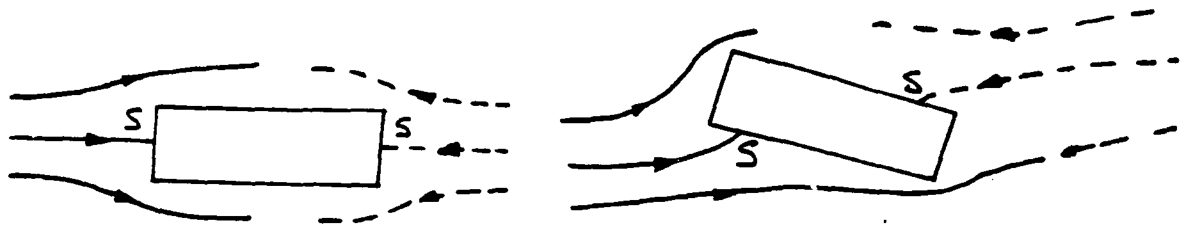

Figure 2.4 Flow Pattern and Fluid Forcing
____________ Wind Stream; -------- Current

Figure 2.4(b) shows that a small perturbation will have a destabilizing effect which will turn the ship further away form its original undisturbed position. Thus the boat will turn its broadside into the wind provided a steady wind prevails.

With the above elucidation, leeway formulas (2.3) can be used to predict the person-in-suit drift. The next task is to determine drag coefficients for flow over above-water-body and below-water line-body. The approach is through laboratory measurement. The topic is addressed in Chapter 3.

CHAPTER 3

LABORATORY MEASUREMENT

3.1 The experiments carried out required that the person model be subjected to wind and current and the drag force on the model be measured. The tests were carried out at the Water Channel Facility of Center for Applied Stochastics Research at Florida Atlantic University. The model attached to a cantilever beam is placed at face-up position partially submerged. The force inserted by water current is measured to obtain force coefficient on the submerged portion of the body. The model is also placed at face-down position partially submerged. The current force on the model could then be measured to obtain force coefficient for the wind exerted portion of the body.

3.2 Water Channel Test Facility

A water channel laboratory has been built for wind engineering research at the Center for Applied Stochastics Research of Florida Atlantic University. The channel is made of plexiglas to

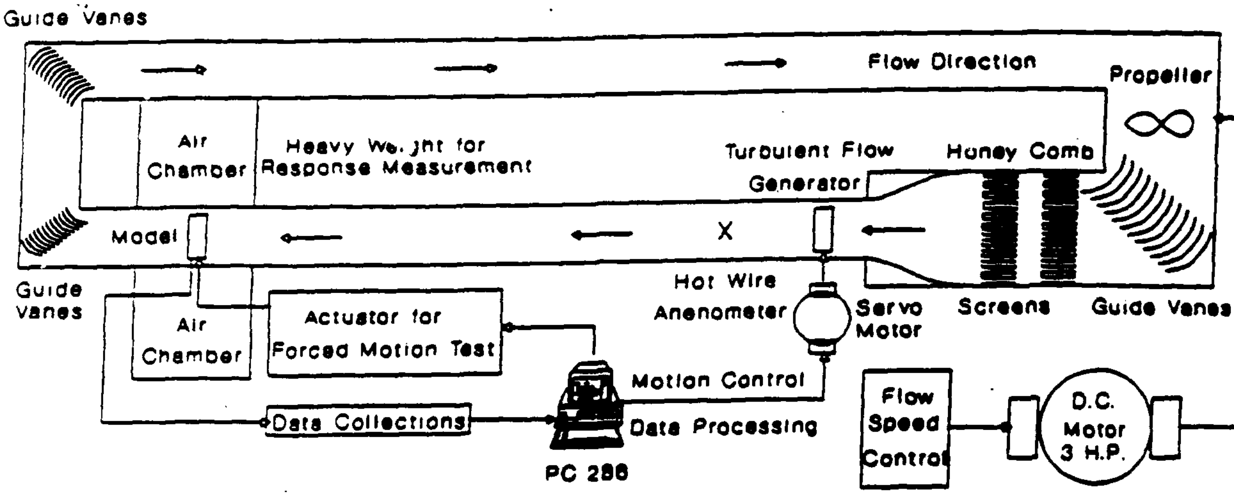

Fig. 3.1 Sketch of Water Channel of Center for Applied Stochastics Research at Florida Atlantic University.

facilitate the experimental observations (Fig. 3.2). A variable-pitch propeller, driven by a 3-horsepower DC motor, recirculates the water flow. The DC motor is controlled by an SCR-type controller, which converts the 230V AC power to a DC voltage adjustable from 0~130V, with a maximum current of 16A. By changing the input voltage of the motor, the rotating speed of the propeller can be adjusted, and the longitudinal flow speed can be varied from 0 to 0.5 meter per second. Higher speed can also be obtained by varying the pitch. Through the visual aid of hydrogen bubbles, the flow in the test section is seen to be smooth and approximating a uniform laminar flow. Hydrogen bubbles are generated from a straight platinum wire of 25 μm in diameter, connected to the cathode of a pulsating electric current source. Flow speeds were calibrated using the hydrogen bubbles, and the distances between adjacent time lines were measured. These distances, together with the corresponding time intervals at which the hydrogen bubbles were generated, were used to compute the flow speeds. The relationship between the DC motor input voltage and the corresponding average flow speed was found to be nearly linear.

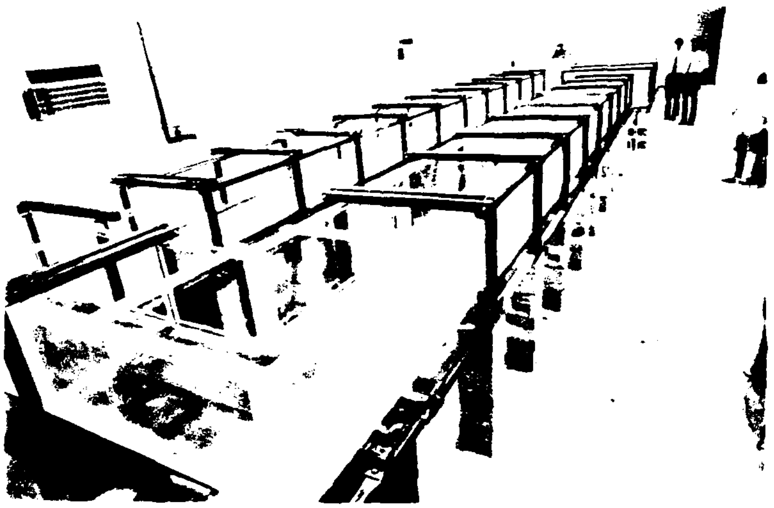

Figure 3.2 Overall Look of the Water Channel

Transducers of the non-contact eddy-current type are used for measuring the force on the model by detecting small displacement of an elastic linkage which supported the model. They are highly sensitive and are capable of detecting very small displacement without disturbing the model. Each transducer has a sensing element which is 5 mm in diameter with the following main characteristics: measuring range of 1.25 ~2 mm, sensitivity 8 mV/μm, accuracy within 5%, deviation from exact linearity within 20 μm, frequency response between 0~1000 Hz, temperature range of -10~100°C, and output voltage range of 0~16V.

The output of each transducer is transmitted through a shielded multi-conductor cable to a data acquisition board on an AST Premium 286 microcomputer for recording and processing. The data acquisition board, National Instrument Model AT-MIO-16L-9, has 8 channels of analog-to-digital convertors in the differential mode, and is capable of collecting data up to 100,000 samples/sec with a 12-bit precision, which is equivalent to an error range of ±0.025%. Since the highest input voltage of the board is limited to 10V, the output from the transducer, ranging up to 16V in amplitude, is reduced by one-half, using a register-divider for each channel. Several programs have been written in C language for recording data interactively and in batch mode using the LabWindows Data Acquisition Library. These programs were then compiled with Microsoft Quick C for DOS. Through a configuration file, each program is capable of selecting the sampling rate, the specific channels for recording and suitable scale factors, so that the readings reflect the displacement in mm rather than in voltage. The data stored on computer disk can be further processed using other programs, such as DADiSP, GnuPlot on PC and IMSL/FORTRAN on DECstation 5000.

3.3 Test Set Up:

The test device used for this experiment is mainly based on cantilever beam approach i.e. a unique force (F) applied at tip end caused a curved deflection along the beam. With known properties such as spring stiffness (k) and measured deflection or displacement gap, the force (F) can be calculated.

In this case, a (10x1/2x1/8)in. aluminum rigid bar is vertically connected to a (1/2x1/2x3)in. horizontal aluminum block by a single centered bolt which was also used as a pivot so that different angle can be adjusted. The block is also attached to a (2x3x1/32)in. thin steel plate acting as a spring leaf fixed at other end.

A transducer (Eddy-current device) is positioned near fixed end of the spring leaf. When water flows, a force is applied on the test model from which it is being pushed along the direction of the flow. The spring leaf deflected accordingly depended on current speeds. The transducer detected gap changes, measured, converted (to mm) and recorded.

Spring stiffness is found by calibration method. Displacement at certain location where a transducer mounted can be measured and recorded. Fluid force applied on the model then can be calculated.

3.4 Calibration of the Spring Leaf:

With known force and measured displacement, spring stiffness can be calculated. Initially, recorded unload or zero gap change as a reference point. Then, at the tip end of the vertically hanged cantilever bar, connected a known weight of 50 grams such that it pulled a horizontal force which caused some deflection on the spring leaf. Displacement is measured by transducer and recorded. Weight is then substituted with 100 grams, and 200 grams. As results:

Weigh grams	X1 mm	X2 mm	X3 mm	DX1 mm	DX2 mm	DX3 mm	DXm mm
0	.739	.740	.740	0	0	0	0
50	.813	.814	.814	.074	.074	.074	.074
100	.876	.885	.881	.137	.145	.141	.141
200	1.005	1.006	1.019	.266	.266	.279	.270

where:

X1: deflection 1^{st} trial.
X2: deflection 2^{st} trial.
X3: deflection 3^{rd} trial.

DX11 = X11 - X11 DX21 = X21 - X21 DX31 = X31 - X31
DX12 = X12 - X11 DX22 = X22 - X21 DX32 = X32 - X31
DX13 = X13 - X11 DX23 = X23 - X21 DX33 = X33 - X31

DXm = (DX1+DX2+DX3) / 3

It is noted that the relationship between displacement (DXm) and force (W) is linear for the range of small displacement.

From above results, spring stiffness can be found:

$k50 = [\ 50g * 9.8m/sec^2\ ] / .074mm$
$k50 = 6622\ N/m$

$k100 = [\ 100g * 9.8m/sec^2] / .141mm$
$k100 = 6950\ N/m$

$k200 = [\ 200g * 9.8m/sec^2] / .270mm$
$k200 = 7259\ N/m$

$k_{avg} = 6944\ N/m$

Now applied forces can be found with the spring stiffness and measured deflections caused by fluid flows.

3.5 Test model and procedure:

In water-channel lab, a fully dressed, rubber mannequin approximately 12 in. in height, 3 in. shoulder to shoulder, is used as a test model which is mounted at tip end of the test instrument. (Figures 3.3 & 3.4)

Figure 3.3 Test of Person-in-suit floating in water

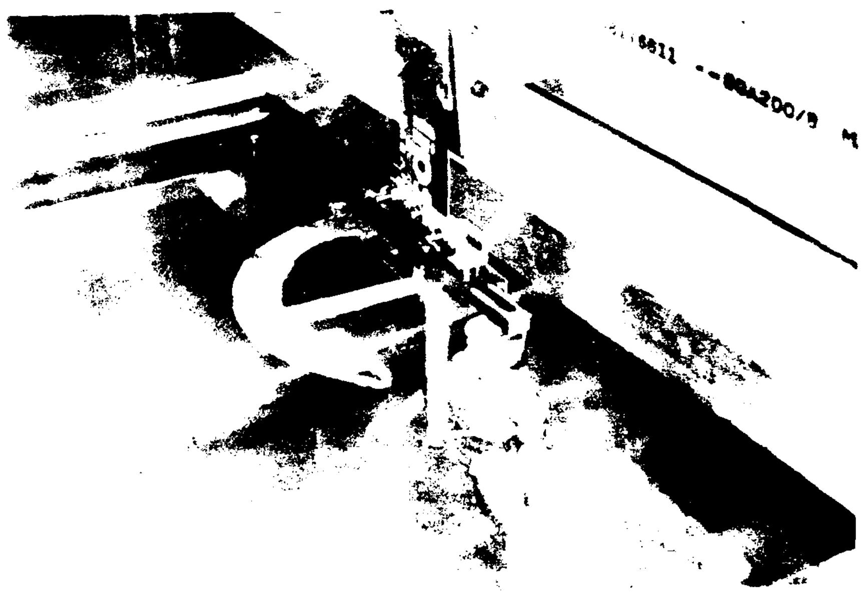

Figure 3.4 Test of Person-in-water without wearing survival suit

The model is partially submerged in water and resumes the natural position of a person afloat in water facing up. The model is also being tested in different styles such as facing down, laying flat, vertical, and side way against current flows. For each particular style, the test was carried out with controlled water current speeds from 0, 10, 20, 30, and 40 cm/sec. In addition to each style, five positions were set for the test from 0, 30, 45, 60, and 90 degrees with respect to current.

3.6 Result Obtained:

The resulting force is normalized to obtain drag coefficient defined as:

$C_D = F / (0.5 * \rho * U^2 * L * T)$

where:

F ≡ drag force
 ≡ k * δx
 ≡ 6944 δx

δ ≡ water density
 ≡ 1000 kb/m^3

U ≡ velocity of water flow

T ≡ average width of model
 ≡ 0.080 m

L ≡ length or height of model
 ≡ 0.300 m

The drag coefficient C_D is tabulated in Table 3.1 for various portions of person-in-water. It is noted that in general $\theta = 90°$ resulted in higher drag coefficient which is to be expected. Also the data of $\theta = 90°$ is the one to be used in obtaining the leeway formula. The effect of speed (i.e. Reynolds number effect) is considered small in light of other uncertainty involved in the person-in-water situation. For the case of U = 40 cm/s, the $N_R = UL/\nu = 1.2x10^5$. The drag coefficient C_D at the speed will be used as a representative figure in obtaining the leeway formula. Without loss of generosity, A_1 and A_2 are chosen to be LT.

Case I <u>Person-in-the-water wearing survival suit</u>.

$C_1 = 0.690$, $C_2 = 0.757$,

$\lambda = \sqrt{C_1\rho_1/C_2\rho_2} = 0.0334$

$\lambda/(1 + \lambda) = 0.0323.$

Therefore, the leeway velocity is estimated to be

$$U_L = 0.0323(U_1 - U_2) \tag{3.1}$$

Case 2 <u>Person-in-the-water without survival suit floating upright</u>.

$C_1 = 0.131$, $C_2 = 0.989$

$\lambda = 0.0127$, $\lambda/(1 + \lambda) = 0.0126$

Therefore the leeway velocity is estimated to be

$$U_L = 0.0126\,(U_1 - U_2) \tag{3.2}$$

Table 3.1 Drag Coefficient for Various Configuration of Person-in-Water.

head Speed angle	10cm/s	20cm/s	30cm/s	40cm/s
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
30.00000	0.1424199	0.1406732	0.1395435	0.1400481
45.00000	0.1126524	0.1173465	0.1237145	0.1376422
60.00000	0.1511503	0.1056965	9.7714439E-02	0.1118149
90.00000	0.1097493	0.1106468	0.1116884	0.1309842
man face down				
0.0000000E+00	0.0000000E+00	0.1548578	0.1917390	0.2036343
30.00000	0.4986044	0.4379889	0.4484979	0.4542461
45.00000	0.6868957	0.5866319	0.6046488	0.6203427
60.00000	0.6944491	0.6772670	0.7497367	0.7408646
90.00000	0.6970068	0.6540224	0.6860859	0.6902429
man face up without cloth				
0.0000000E+00	0.1572674	0.1092426	0.1117169	0.1065138
30.00000	0.1562317	0.1771792	0.1877929	0.1902622
45.00000	0.3634097	0.3031161	0.2837229	0.2981239
60.00000	0.4868223	0.4075293	0.4108255	0.4169101
90.00000	0.5458740	0.4835963	0.4823158	0.5113845
man face up with cloth				
0.0000000E+00	0.2299411	0.1927991	0.1867200	0.1830551
30.00000	4.4563189E-02	0.2494550	0.2453340	0.2561134
45.00000	0.5233663	0.4495984	0.4136977	0.3871422
60.00000	1.357366	0.8054999	0.6696532	0.6131807
90.00000	0.8220834	0.7731811	0.7442271	0.7570276
man with cloth vertical position				
0.0000000E+00	0.5601726	0.7057443	0.6429778	0.8021131
45.00000	1.635820	1.414762	1.307862	1.245064
60.00000	2.030592	1.779843	1.711434	1.696182
90.00000	2.033440	1.828054	1.919031	1.834814
man without cloth vertical position				
0.0000000E+00	0.7801026	0.6873937	0.6675763	0.6433603
45.00000	0.9727124	0.9205090	0.8526301	0.8104716
60.00000	1.110624	0.9531762	0.9027336	0.8842856
90.00000	1.198224	1.032139	1.011765	0.9889957

CHAPTER 4

FIELD TESTS

4.1 Introduction

A field experiment was conducted by Florida Atlantic University to provide a benchmark set of field data for the calibration and verification of drift prediction model, equation (3.1). The experiment was conducted on February 27, 28 and March 6, 7, 1993 along the coast off Long Key, Florida. The tests on February 27, and 28, 1993 took place in the Florida Bay near Keys Marine Laboratory. While the tests on March 6 and 7, 1993 is in Atlantic Ocean along Long Key Viaduct. The Keys Marine Laboratory (KML), a joint operation of Florida Marine Research Institute, Florida Department of Natural Resources and the Florida Institute of Oceanography provided logistical support. KML was the staging area for the test team. Two 24' T-Crafts with 7 person capacity was provided by KML.

4.2 Experiment Design

4.2(a) Experimental Area

A 1 by 1-nautical mile area, centered in Florida Bay off Keys Marine Laboratory, Layton Florida was the tracking range during the experiment (see Figure 4.1) of February 27 and 28, 1993. A 1 by 1-nautical mile area, centered in Atlantic Ocean off northern end of Long Key Viaduct was the tracking range (See Figure 4.2) during March 6 and 7, 1993. The exact locations for deployment of drifters and test craft was determined by the expected tidal current and winds for that day.

4.2(b) Drift Targets

Three mannequins are equipped in survival suit to simulate person-in-water drifting target (Figure 4.3). Mr. George Janssen II, a senior in mechanical engineering volunteered in the real person drift in the test on February 27, 1993 (Figure 4.4).

4.2(c) Position Measurement

The position of drift targets and drifters was tracked by triangulation using transits. Two land based tracking teams were set up. Each team consisted of two transits and their operators. Each team was responsible for tracking one drift target and three accompanying current-measurement-drifters. A walky-talky was issued to each operator and leader of each tracking team to synchronize their measurement by aiming on a certain target simultaneously through microwave communication. On the average, triangulation took place every two minutes.

Every ten minutes a complete set of position measurements for drift target and accompanying three drifters was made. So long as the drift target stayed in the tracking range, positions for target and drifters were recorded every ten minutes.

Figure 4.1 Experiment Area - Feb. 27 & 28, 1993

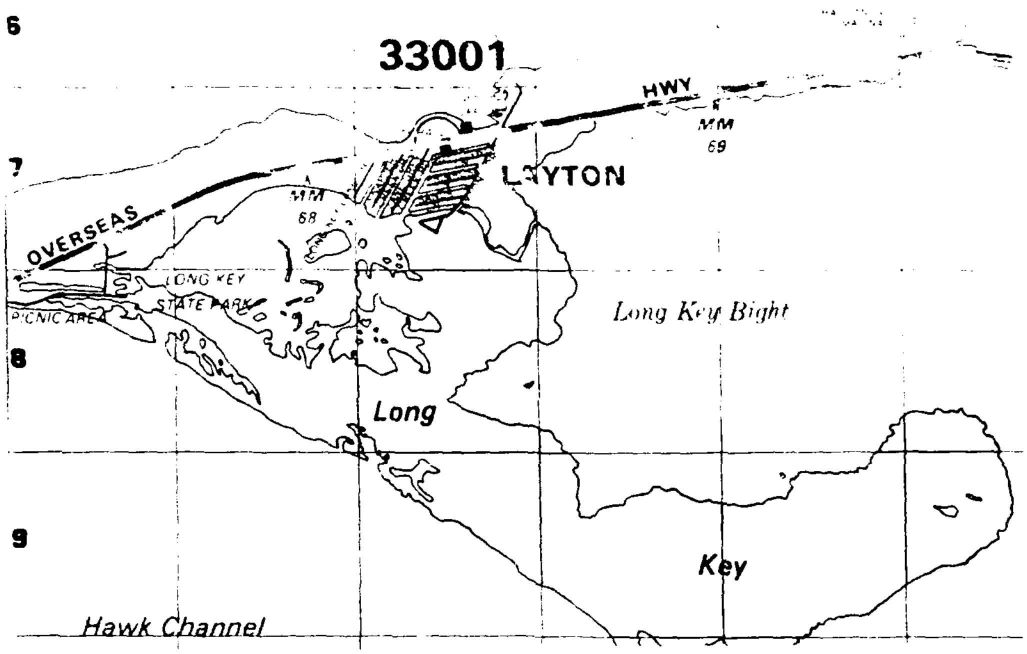

Figure 4.2 Experiment Area - March 6 & 7, 1993

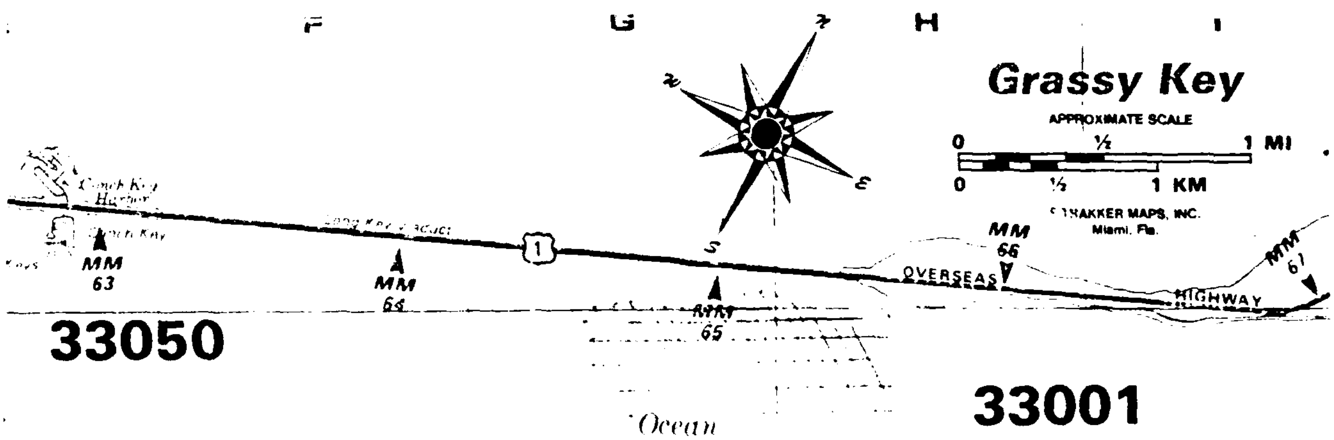

Figure 4.3 Mannequins in Survival Suit

Figure 4.4 Real Person Drift

4.2(d) Current Measurement

The current field near the person-in-water was determined from the position records of a set of Lagrangian drifters deployed around the person-in-water. The person-in-water and drifters were deployed quickly. As the person-in-water was drifted apart from drifter due to wind action, the drifter was redeployed near the person-in-water. When the drift target was out of the tracking range, the drift test discontinued.

The drifters for this experiment are based on an entirely new design. The typical drifters are a floating plate and lay horizontal on the water surface. They are bulky, vary their orientation in currents, and heave in waves. Therefore they are often disintegrated in wave slamming. The changing orientation in currents produce a complicated flow field and raises the doubt about whether the drifter is faithfully following the current.

The new drifter design is based on the property of stagnation flow shown in Figure 2.3. That is, the plate will turn its broad side into the current. Therefore, the drag plate is laying vertically instead of horizontally. A weight is attached to the bottom and two short floaters on top to ensure the drag plate is upright and submerged, (Figure 4.5 ~ 4.8). As in conventional design, there is an antenna stick up for tracking and there is also a container for power and an instrument (in a horizontal cylinder) attached to the drag plate. They were light and strong - easily deployable and recovered by one person, (Figures 4.9 ~ 4.12). Each drifter is designed, tested, and constructed at Florida Atlantic University. It is made of plywood. They were designed as dispensable items for one-time use. Seven drifters were built. There was no loss, no damage of the drifter during the test. The set of drifters deployed together moved together in parallel (Figure 4.13). The design concept is therefore substantiated. The drifter tilted in the wave (Figure 4.14), instead of being slammed in the wave. With an on-board flow sensor, this periodic tilting could be measured and recorded to produce local wave data.

4.2(e) Wind Measurement

Hourly wind information was available from the nearby environmental monitoring (station LONF[1], Code Name S-16) located one mile off shore (LAT. 24.52N, LONG. 80.51W). The station is part of NOAA's Coastal-Marine Automated Network (C-MAN) (C-MAN Users Guide 1992). Wind sensor is 20 ft. above the mean sea level.

4.3 Data Set

Personnel in two boats worked independently with their on-land tracking team. Each boat had a boat captain, one graduate research assistant and two undergraduate assistants. Tracking teams consist of four graduate research assistants, each operating a transit. Nineteen drift sequences were measured. Field data are summarized in Table 4.1.

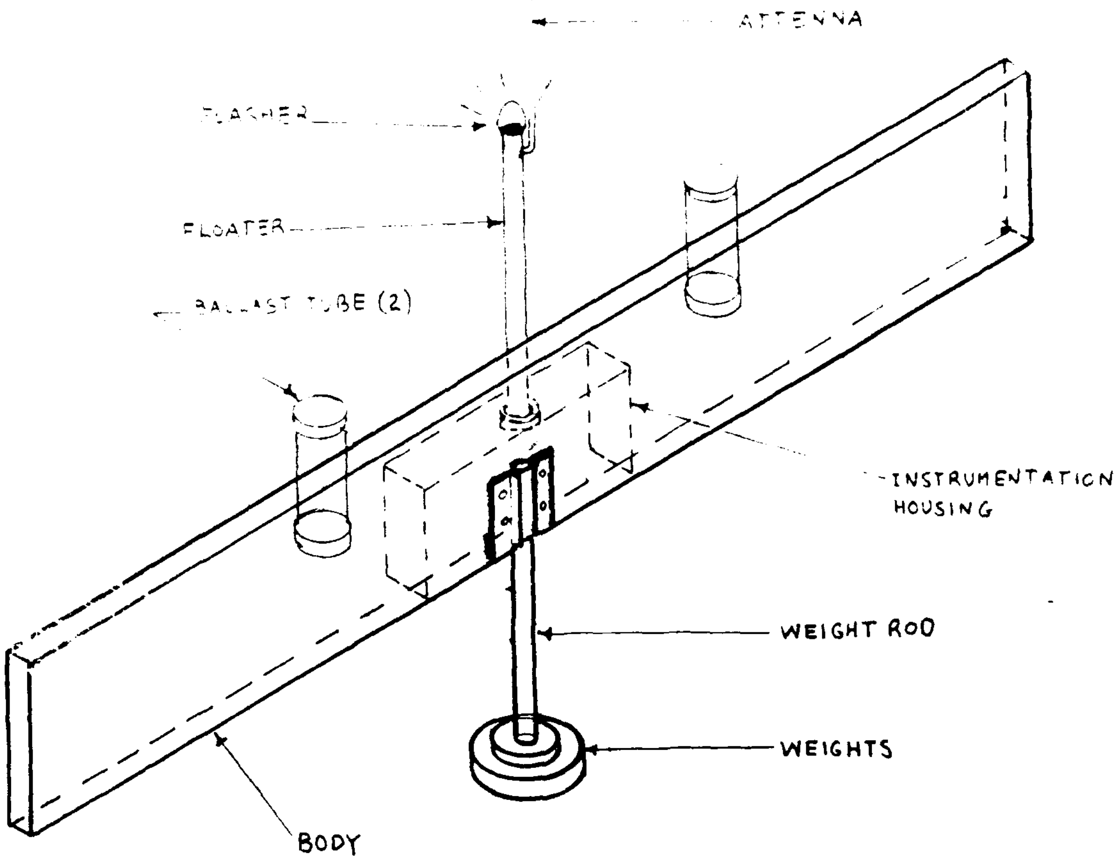

Figure 4.5 Drifter Assembly

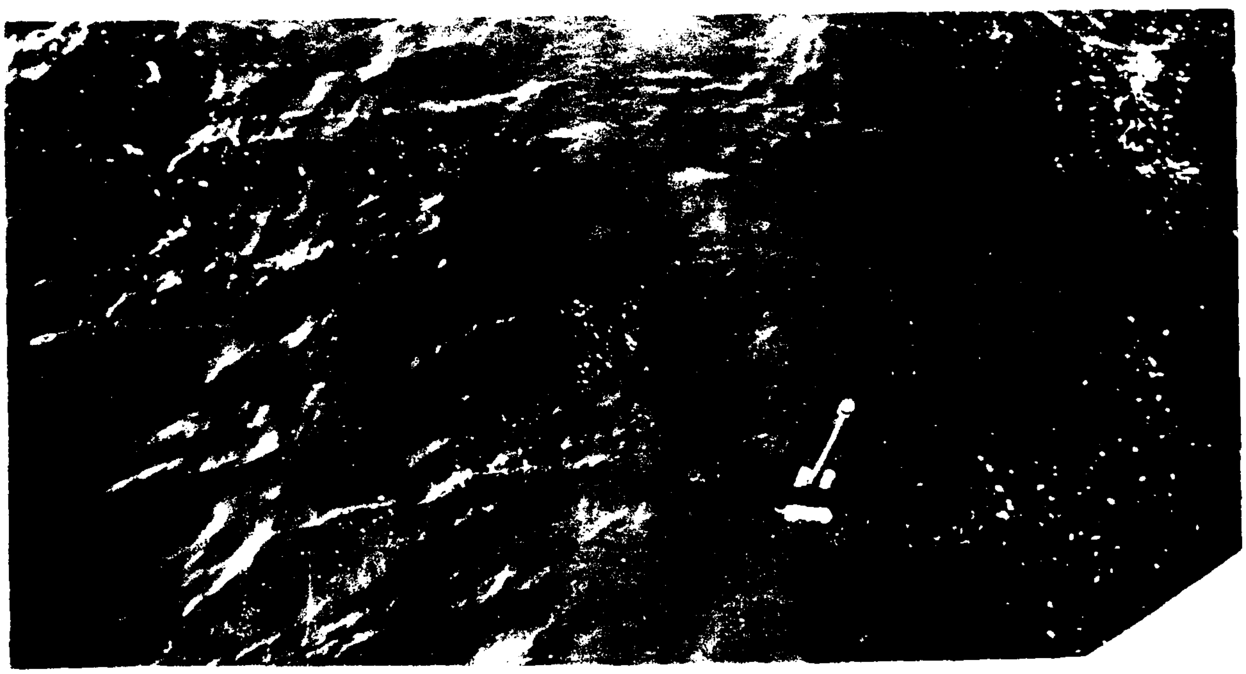

Figure 4.6 New Type of Drifter in Action

Figure 4.7 New Type of Drifter in Action

Figure 4.8 New Type of Drifter in Action

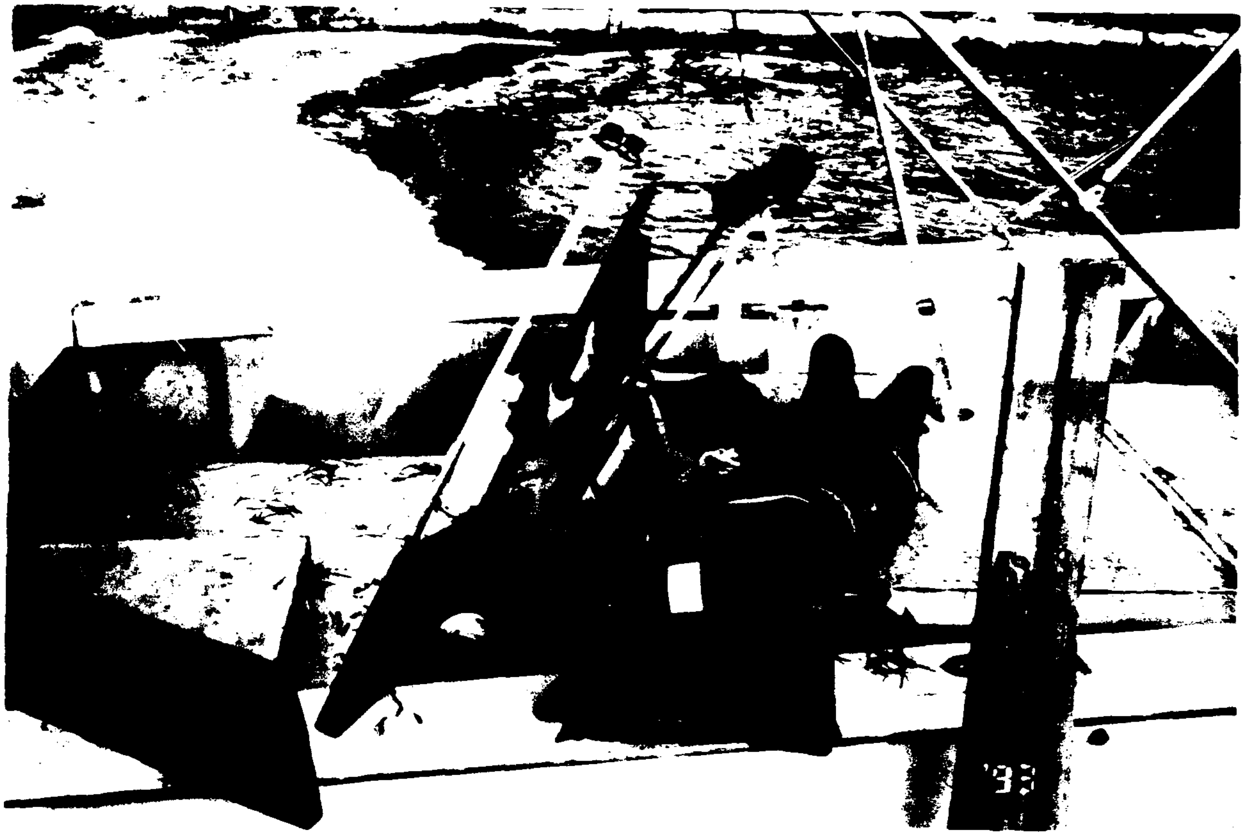

Figure 4.9 Drifter Transport

Figure 4.10 Drifter Deployment

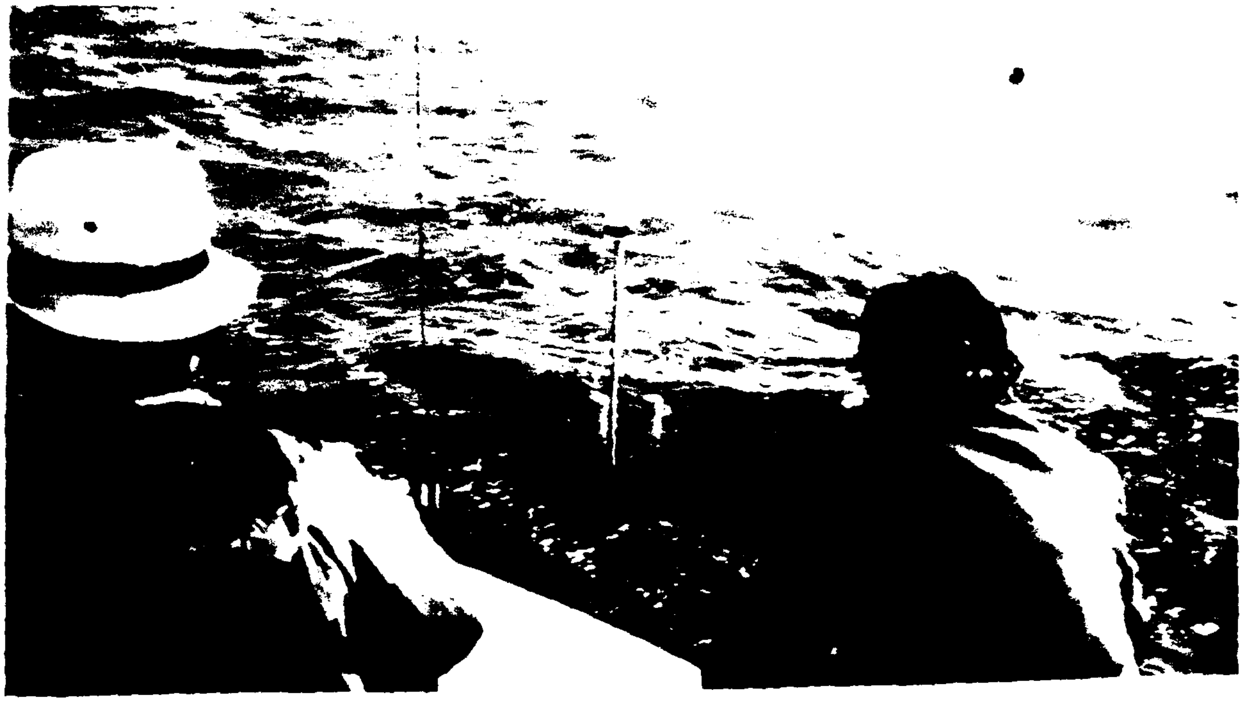

Figure 4.11 Drifter Deployed

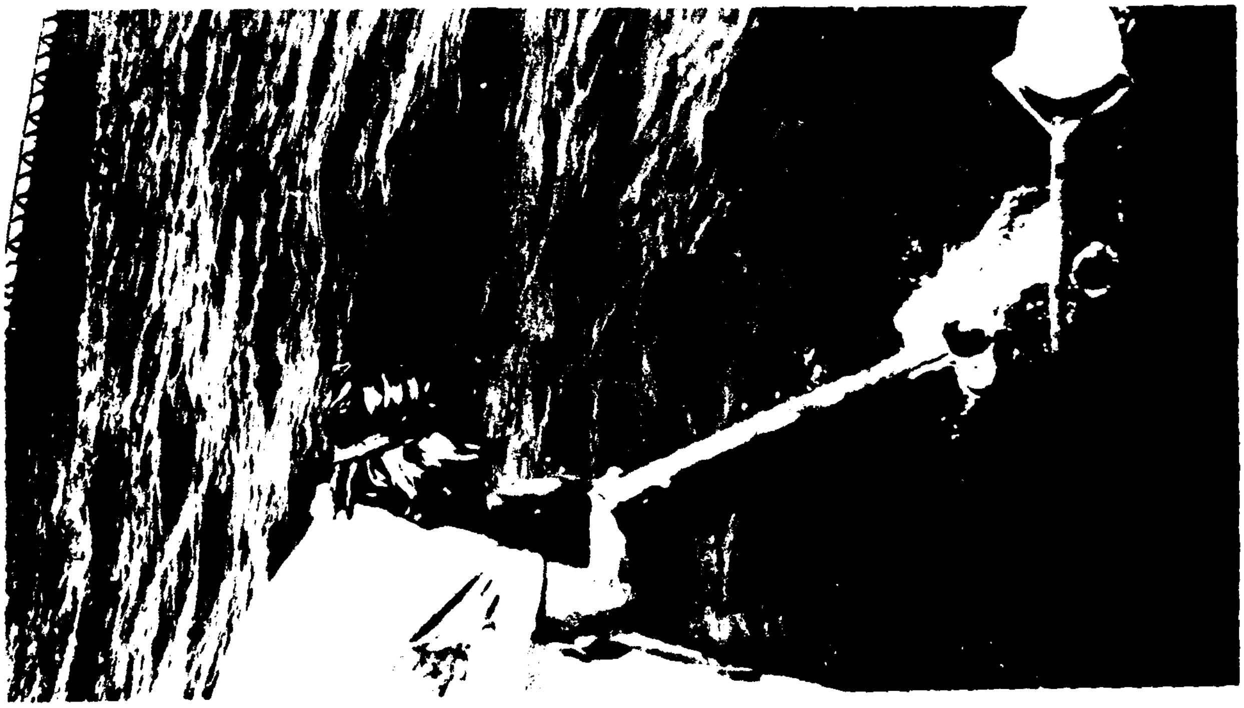

Figure 4.12 Drifter Recovered

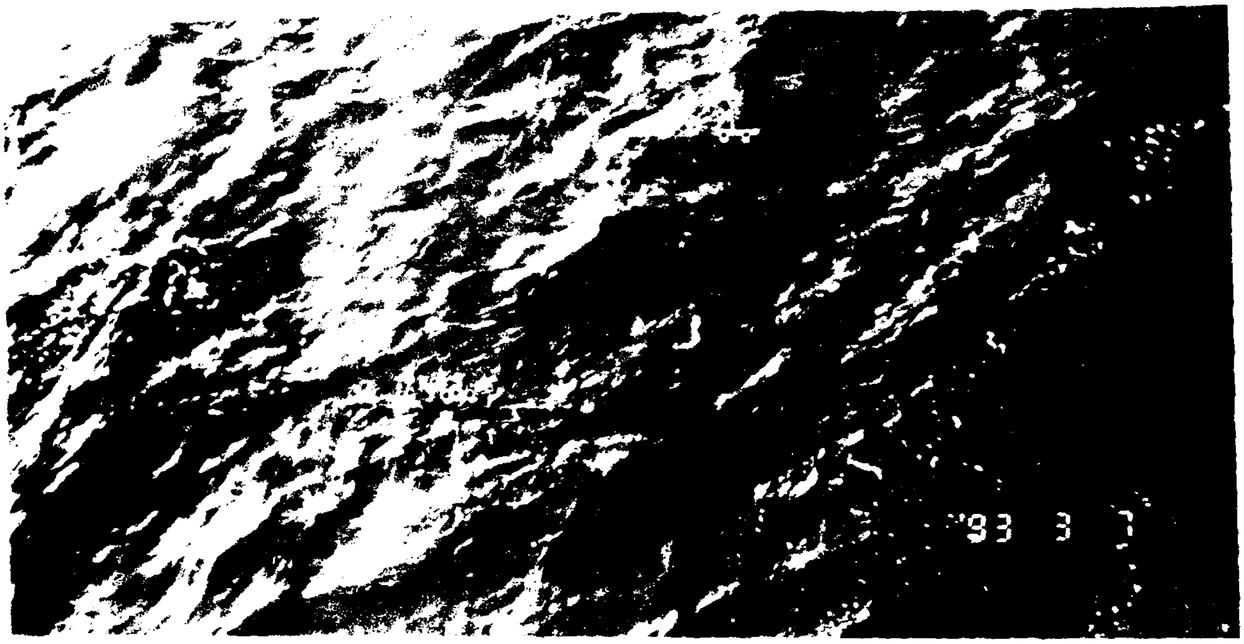

Figure 4.13 Drifters Move in Parallel in Uniform Current

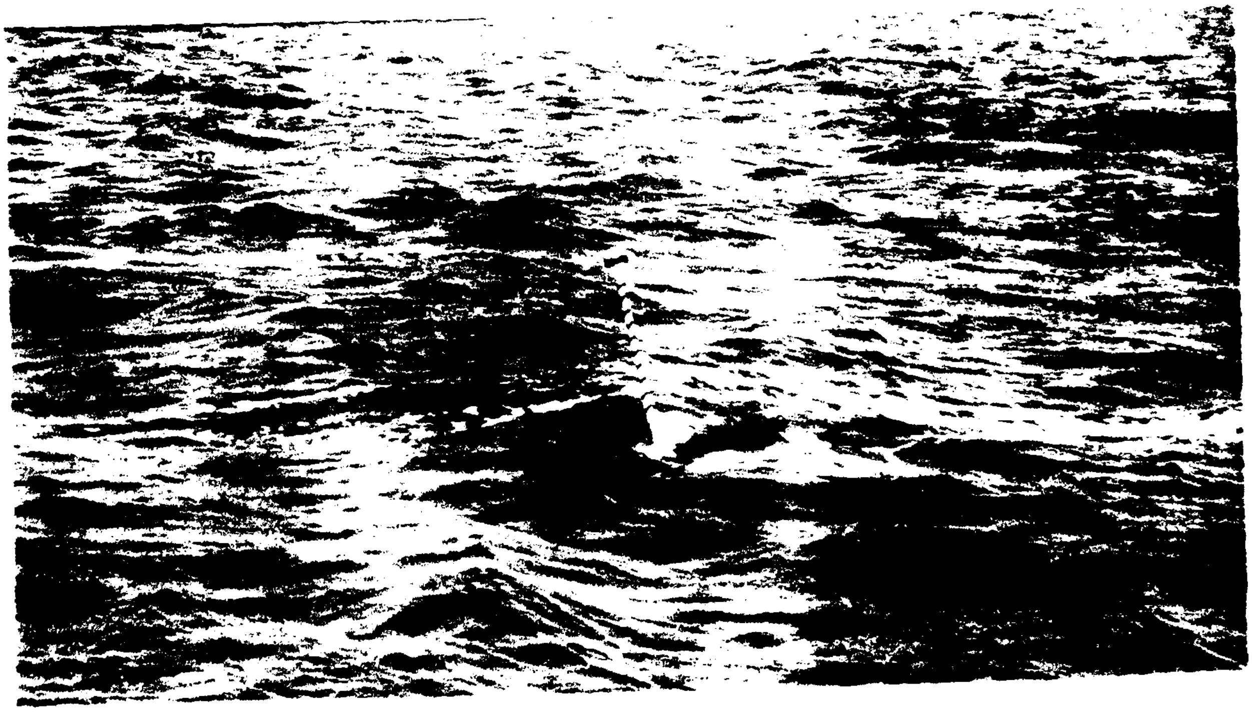

Figure 4.14 Drifters Tilted in Waves

Table 4.1 Field Data Sets

DATA NAME	TEST DATE 1993	TIME	DURATION	No. of DATA SET	No. of COMPLETED DATA SET
A-1-B**	2/27	9:58-12:25	143	16	12
A-2-B	2/27	13:00-14:40	100	12	8
A-3-B	2/28	8:55-10:45	110	10	8
A-4-B	2/28	10:55-14:15	200	21	15
A-5-O***	3/6	9:55-11:45	110	12	8
A-6-O	3/6	12:20-14:40	140	15	11
A-7-O	3/7	9:05-9:35	30	4	3
A-8-O	3/7	9:50-13:50	240	25	19
B-1-B	2/27	9:55-11:25	90	11	9
B-2-B	2/27	12:20-14:00	100	10	8
B-3*-B	2/27	14:30-15:00	30	4	4
B-4-B	2/28	8:55-10:05	70	8	7
B-5-B	2/28	10:40-12:08	88	10	9
B-6-B	2/28	12:40-14:26	106	11	10
B-7-O	3/6	9:40-10:35	55	6	6
B-8-O	3/6	10:55-12:15	80	7	6
B-9-O	3/6	12:42-14:34	114	10	8
B-10-O	3/7	9:35-10:20	45	5	5
B-11-O	3/7	10:35-13:03	148	15	13

* Real-Person Drift

** "B" denotes test at Florida Bay

*** "O" denotes test at Atlantic Ocean

Chapter 5

MODEL CALIBRATION AND MODEL VERIFICATION

5.1 Field Data Set

The major objective in the field test of Spring 1993 was to secure a field data set for comparing the drift path of person-in-water with predicted drift obtained by the theoretical formula Equation (3.1). The other purpose of the experiment was to better understand the leeway movement of person-in-suit as it applies to search and rescue. It was visually confirmed that the person-in-suit tend to turn it broadside to the wind. The field data summary is given in Table 4-1.

5.2 Wind Data

The wind was measured at a height of 20 feet above mean sea level. Wind data in the tracking range during the test period is given in Table 5.1.

We assumed that the absolute wind profile obeys the 1/7th power law.

i.e.

$$U_1(z) = \left[\frac{z}{z_R} \right]^{1/7} U_{1R} \qquad (5.1)$$

Where Z is the elevation measured from the sea surface, U_{1R} is the wind speed measured at the reference height Z_R (= 20 feet) and $U_1(z)$ is the wind speed at height Z. The effective wind speed on person-in-suit is estimated to be 0.6 ft. Therefore, following (5.1), 60% of the measured wind was used for the wind action on person-in-water suit floating in water.

5.3 Position of Person-in-Water and Surrounding Current

The time history of movement of Person-in-suit is tabulated in Appendix I for each of the 19 test cases. Also listed in the tables are the current velocity interpolated from movement of three drifters and wind velocity interpolated from hourly wind data.

In Appendix II Field Data Plot, trajectories of search target and drifters are plotted for each of the 19 test cases. It was noted that for these tests in the Florida Bay, the drifter's trajectories is zigzagging, indicating the presence of small scale eddies over the drifting range. Therefore, the current velocity interpolated from movement of three drifters is not accurate and can't be used as base of prediction.

5.4 Model Verification

For each of the 9 cases tested in the Atlantic Ocean, the drift path was predicted using Equation (3.1). The predicted drift and the corresponding measured drift are compared for each case. The deviation is normalized by the distance of actual drift and expressed as a percentage error. The result is shown in Figures 5-1 through 5-9.

TABLE 5.1 WIND DATA

DATE	TIME	SPEED (miles/hr)	DIRECTION (degree)
2/27/93	8:00	21.7	343
	9:00	18.1	352
	10:00	17.6	360
	11:00	13.6	355
	12:00	8.3	345
	13:00	4.9	329
	14:00	6.6	343
	15:00	10.2	297
	16:00	8.5	302
2/28/93	8:00	16.7	20
	9:00	17.7	20
	10:00	16.6	20
	11:00	12.0	7
	12:00	9.9	20
	13:00	8.6	24
	14:00	7.0	14
	15:00	3.3	350
	16:00	3.0	12
3/6/93	8:00	10.4	360
	9:00	12.4	19
	10:00	10.9	31
	11:00	6.9	13
	12:00	7.5	20
	13:00	5.5	53
	14:00	5.6	47
	15:00	5.3	43
	16:00	6.7	112
3/7/93	8:00	12.8	23
	9:00	13.6	54
	10:00	12.1	52
	11:00	11.5	78
	12:00	11.2	79
	13:00	8.4	75
	14:00	6.0	54
	15:00	5.4	33
	16:00	2.9	205

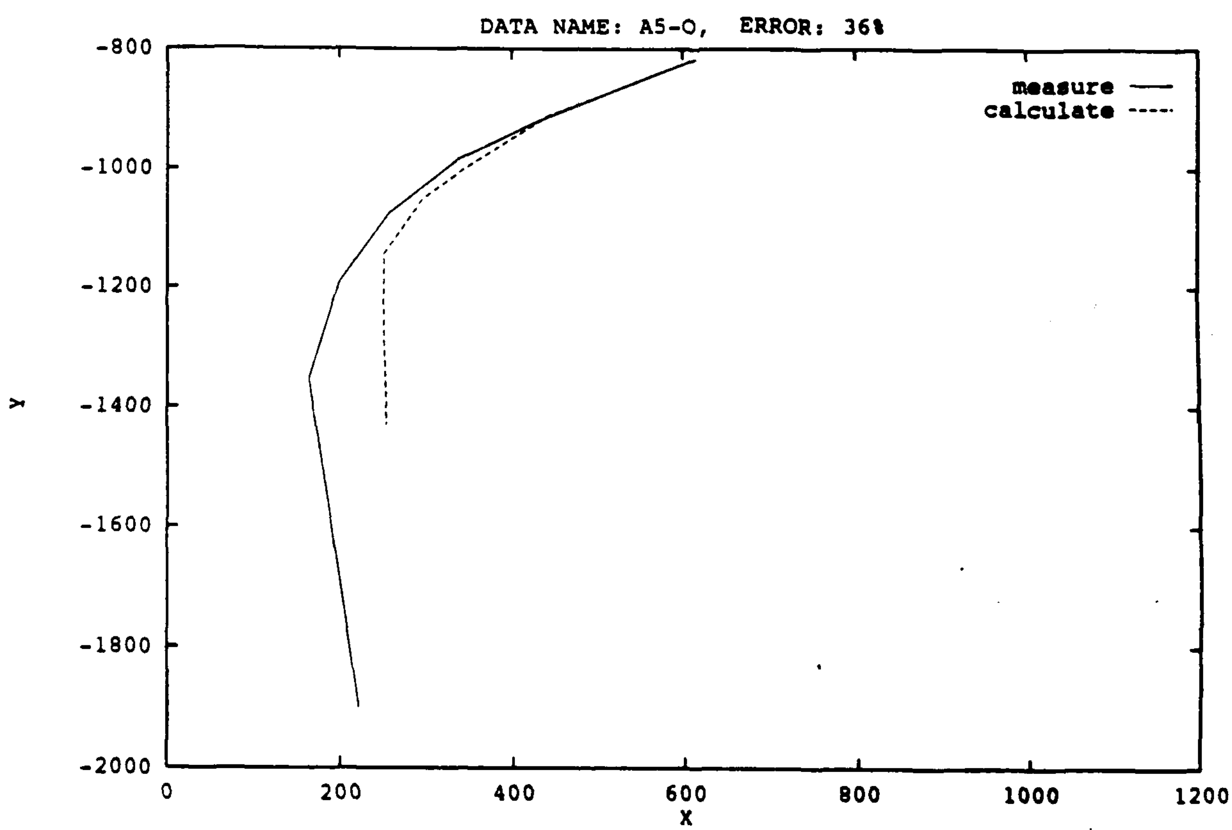

Figure 5.1 Model Verification

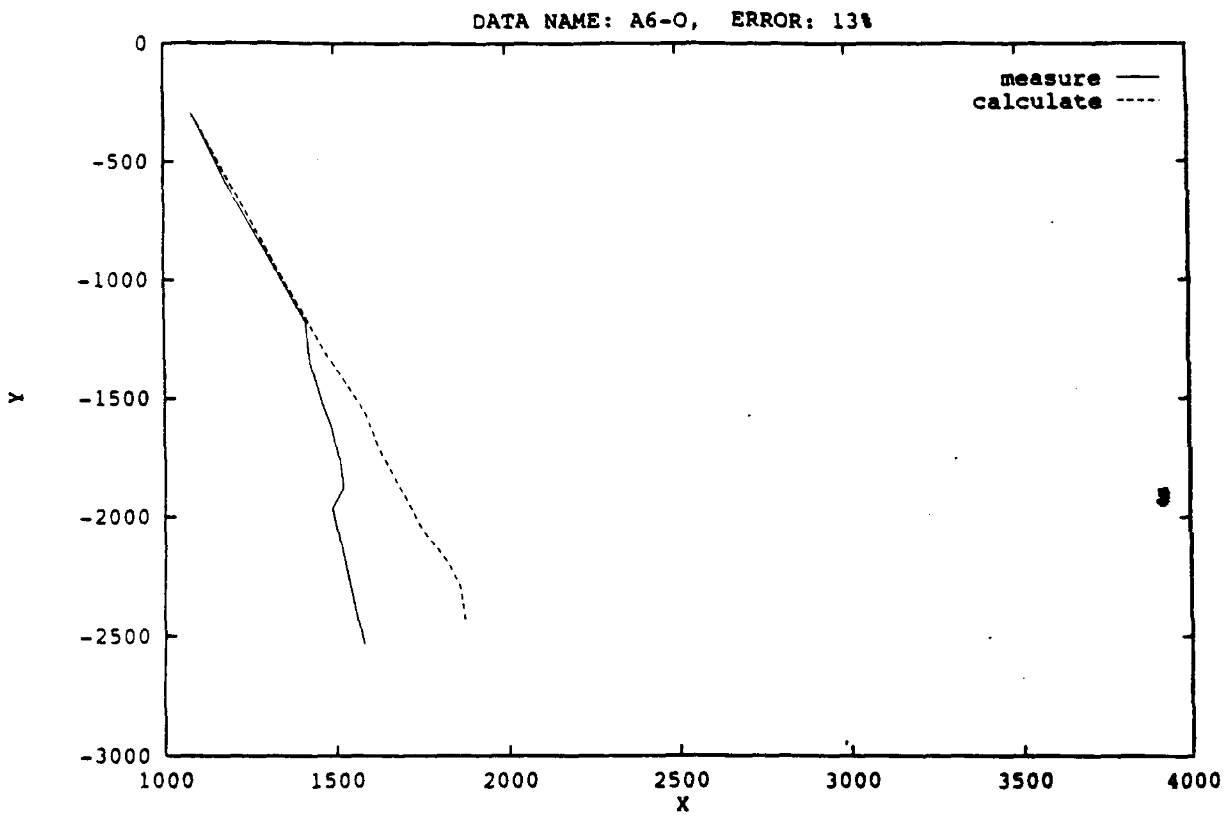

Figure 5.2 Model Verification

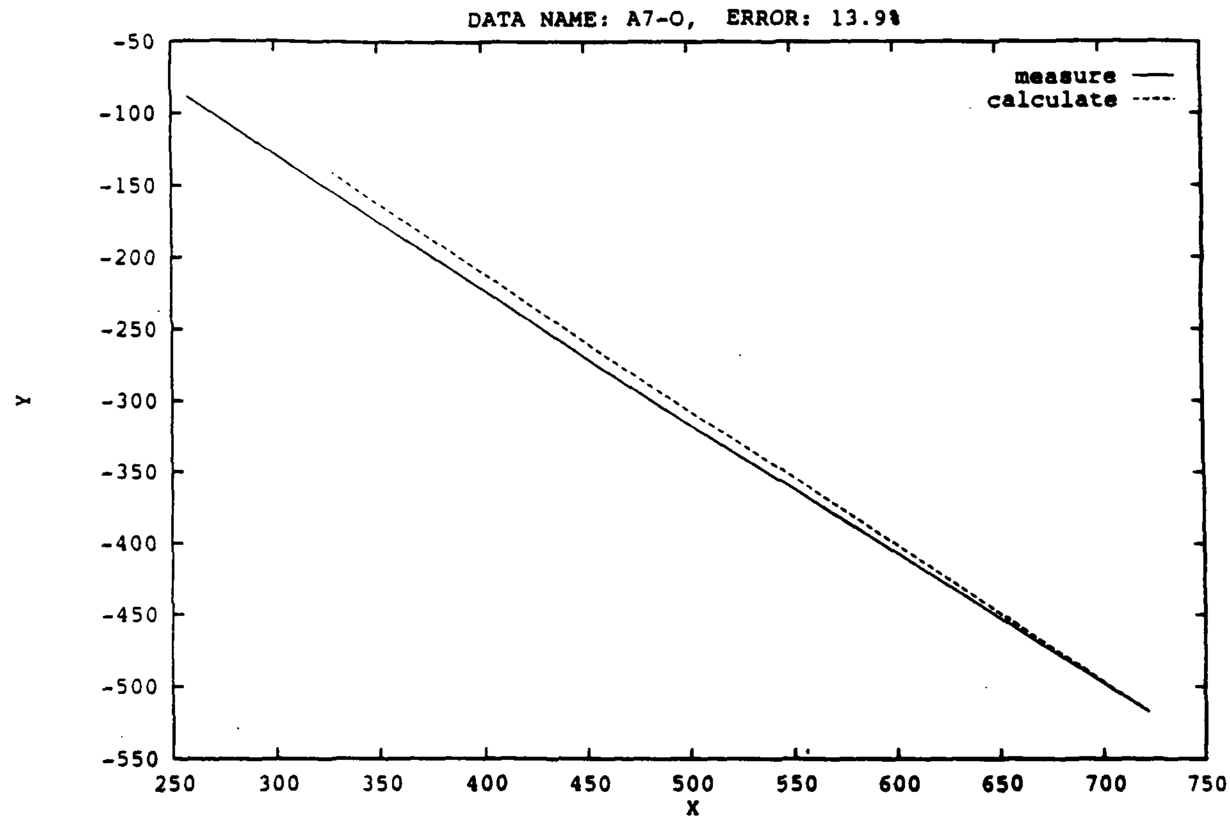

Figure 5.3 Model Verification

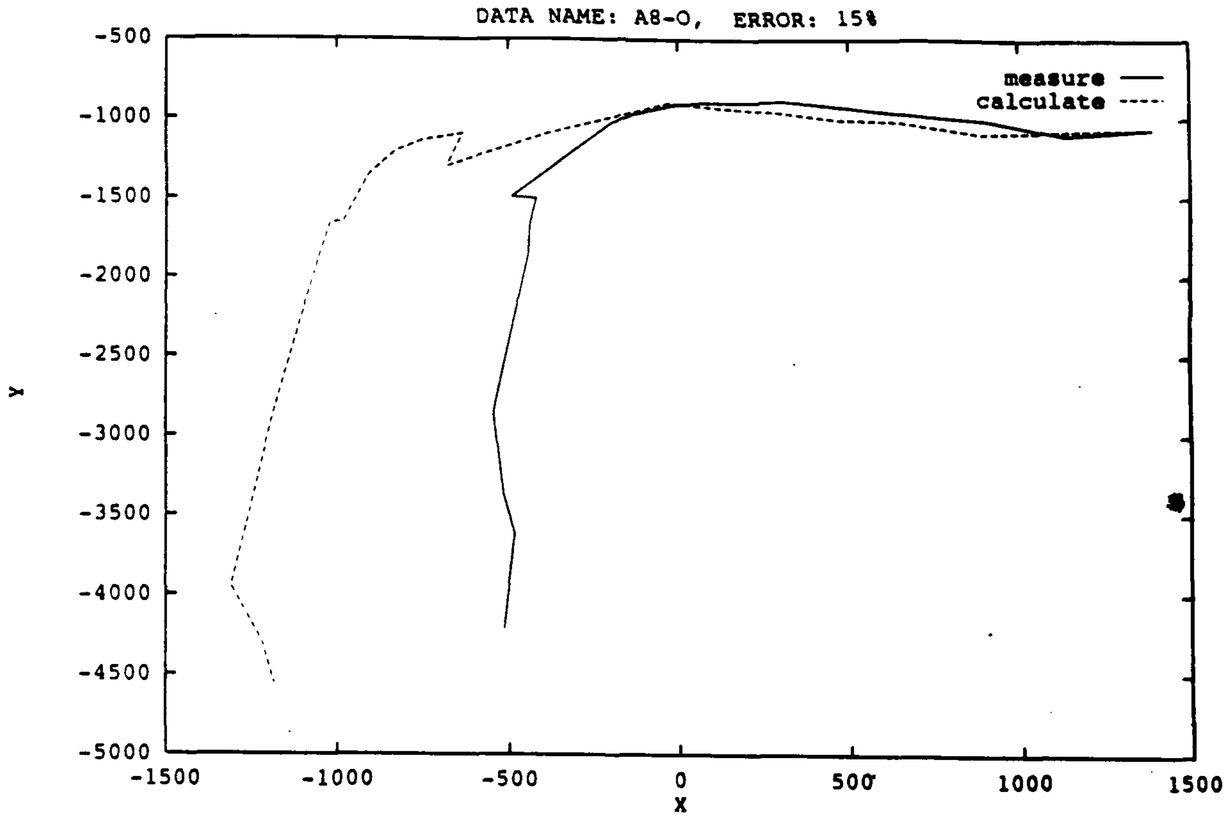

Figure 5.4 Model Verification

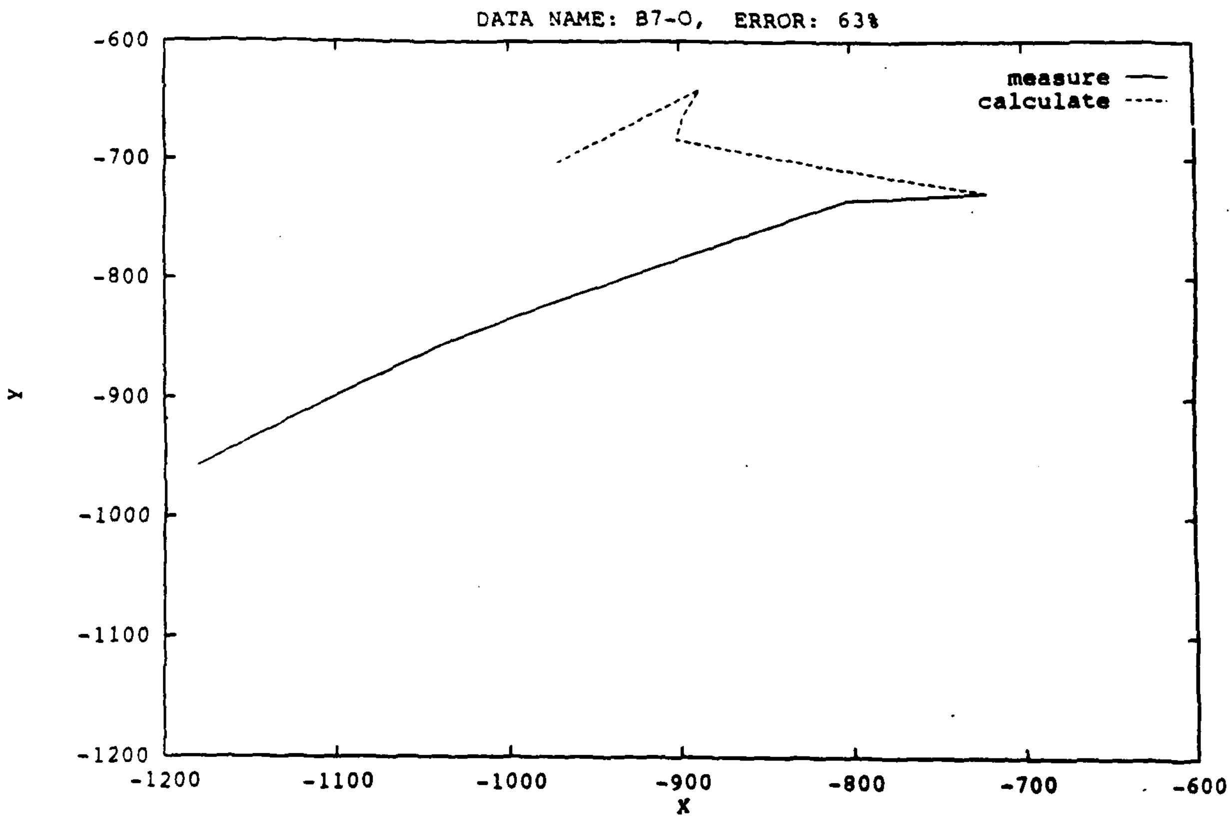

Figure 5.5 Model Verification

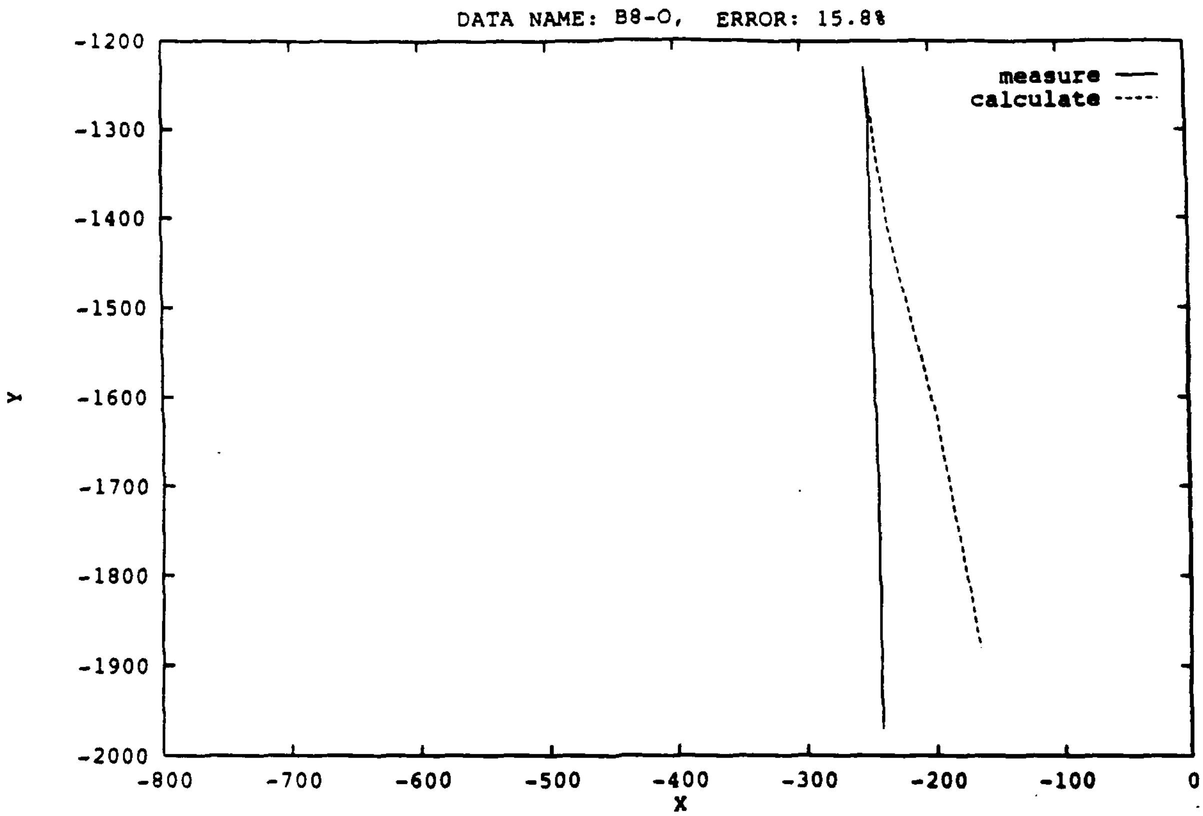

Figure 5.6 Model Verification

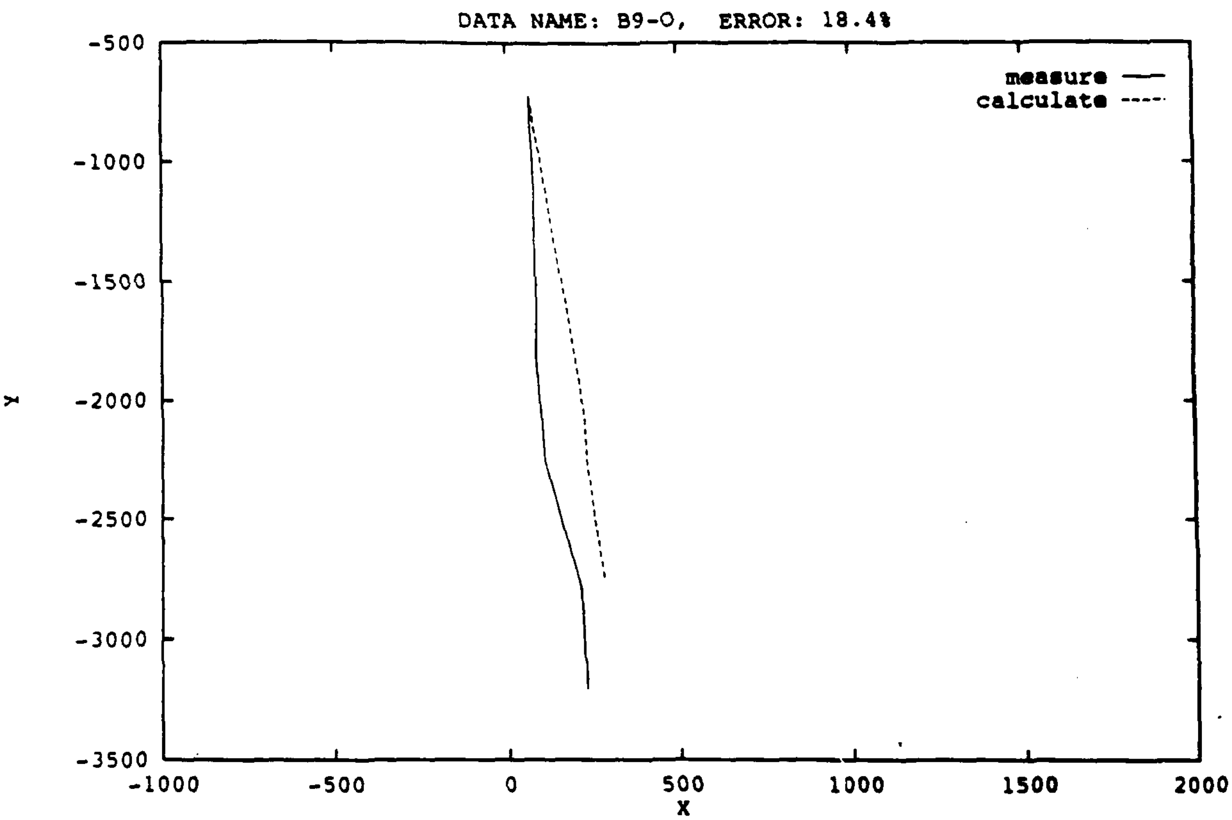

Figure 5.7 Model Verification

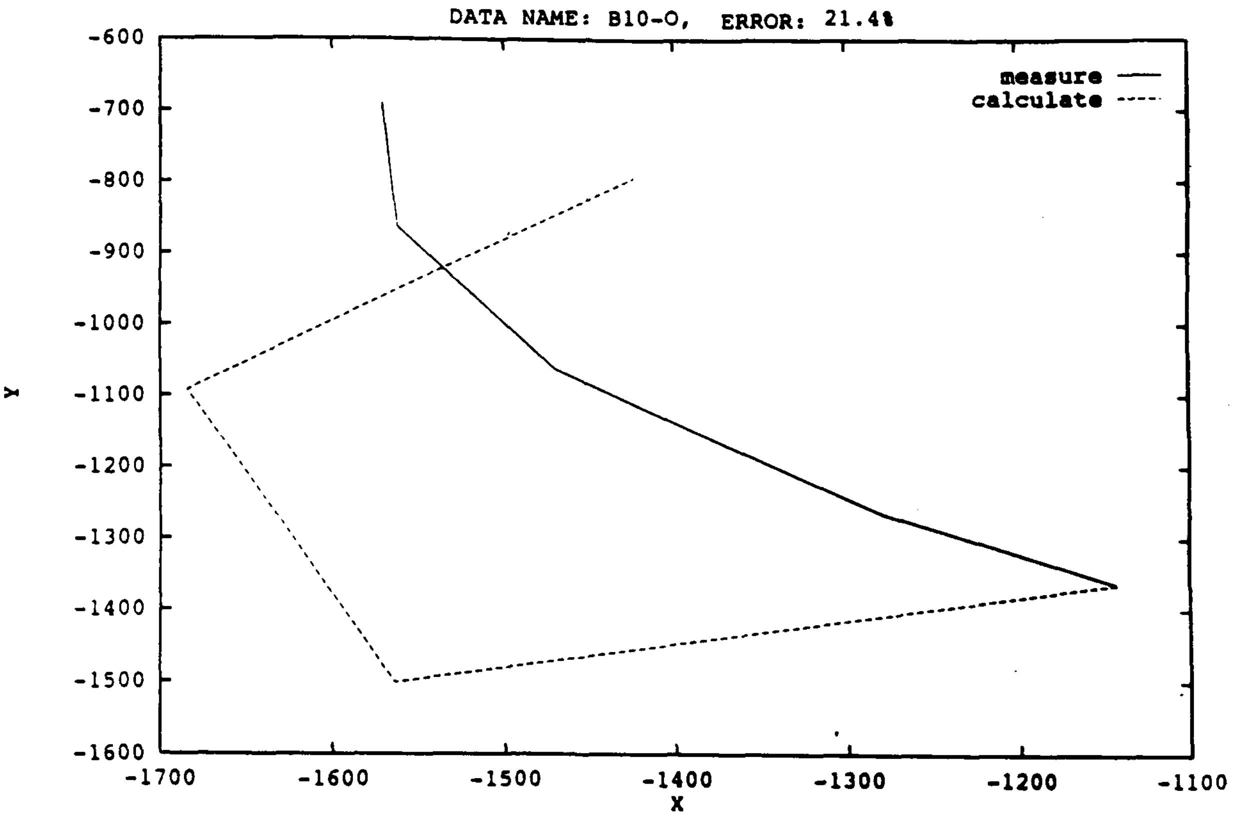

Figure 5.8 Model Verification

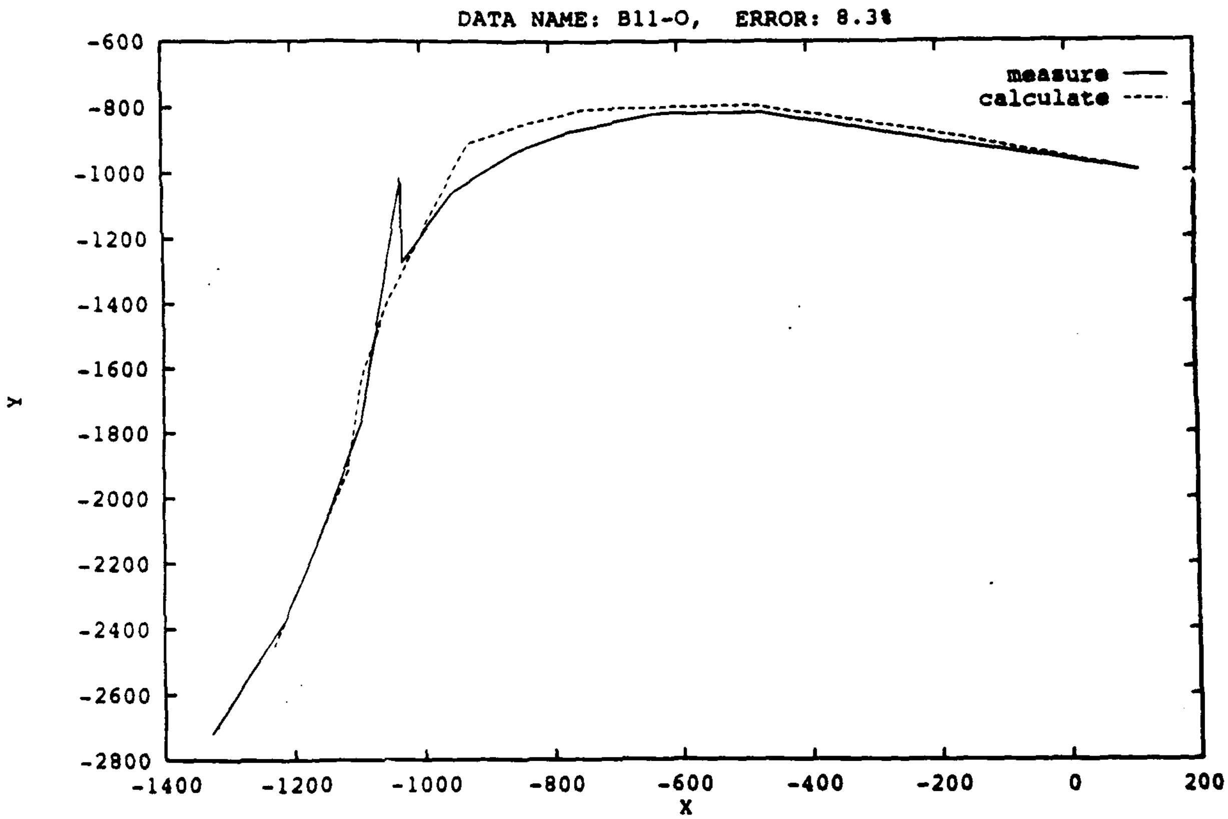

Figure 5.9 Model Verification

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. A simplified leeway formula developed from theoretical considerations, indicates that the leeway velocity is directly proportional to the apparent wind (relative to the current) velocity in wide range of wind speed ranges.

2. The proportional constant was evaluated in laboratory tests. From which the leeway velocity is estimated to be

$$U_L = 0.0323(U_1 - U_2)$$

for person-in-the-water wearing survival suit. The proportional constant (the leeway factor) reduced to 0.0126 for person-in-water without survival suit. U_1 should be evaluated at the height of 0.6 feet above mean-sea-level according to 1/7 power law (5.1).

3. Field test was carried out for model verification. The excellent agreement was obtained.

4. The procedure for leeway prediction established in the present study can be extended to determine drift character of other search and rescue targets.

5. A new type of drifter for current measurement was developed and field tested. It offers significant advantages over traditional design.

6.2 Recommendations

1. The mathematical model developed should be inputted into the Computer Assisted Search Planning Systems (CASP). Its performance should be documented for its continuing improvement and evaluation.

2. Air-deployable drifter design for environmental now casting should be pursued. The drifter design concept developed in the present study could lead to a satellite-based environmental monitoring and target tracking system for search and rescue operations.

3. Stormy weather leeway should be investigated. It appears that flow eddies of various sizes contribute in target drift and the extent of target scattering will need to be investigated. The concept of leeway factor needs to be reconsidered.

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APPENDIX I

FIELD DATA SET

\# DATA: 02/27/93
\# Data Name: A1-B

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	9.55	-634.0	547.3	0.0071	-0.0399	0.0918	-7.8865
2	10.15	-613.0	460.3	0.0071	-0.0399	0.1619	-7.4196
3	10.35	-609.7	290.2	0.0283	-0.0653	0.3473	-6.8164
4	10.45	-622.1	226.9	0.0182	-0.0658	0.4269	-6.5132
5	10.55	-639.3	177.8	0.0182	-0.0658	0.4978	-6.2093
6	11.05	-658.3	78.6	0.0723	-0.0793	0.5979	-5.8522
7	11.25	-644.8	-14.8	0.0679	-0.0220	0.8113	-5.0278
8	11.45	-584.5	-100.6	0.0679	-0.0220	0.9314	-4.2010
9	11.55	-565.8	-143.6	0.0205	-0.0304	0.9565	-3.7893
10	12.05	-530.1	-186.1	0.0364	-0.0341	1.0529	-3.4259
11	12.15	-517.4	-234.2	0.0364	-0.0341	1.2072	-3.1042
12	12.25	-479.9	-257.2	0.0465	-0.0315	1.3208	-2.7795

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\# DATA: 02/27/93
\# Data Name: A2-B

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	13.00	-253.7	1109.8	-0.0442	-0.0493	1.4081	-1.6781
2	13.20	-258.3	959.6	-0.0442	-0.0493	1.3071	-2.0650
3	13.30	-276.1	893.8	-0.0664	-0.0121	1.2266	-2.2591
4	13.40	-309.5	777.0	-0.0604	-0.1486	1.1257	-2.4512
5	14.00	-333.4	694.4	-0.0270	-0.1060	0.8627	-2.8217
6	14.10	-362.2	581.1	-0.0270	-0.1060	1.3434	-2.9252
7	14.20	-386.8	484.9	-0.0736	-0.1141	1.8651	-2.9465
8	14.30	-420.8	347.4	-0.0478	-0.1002	2.4139	-2.8768

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\# DATA: 02/28/93
\# Data Name: A3-B

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	8.55	-470.1	833.4	0.0654	-0.2998	-2.6937	-7.4009
2	9.05	-538.8	666.6	0.0654	-0.2998	-2.6924	-7.3974
3	9.15	-590.4	529.7	-0.0227	-0.0803	-2.6644	-7.3204
4	9.25	-659.6	359.5	-0.0379	-0.1217	-2.6364	-7.2434
5	9.35	-714.8	230.9	-0.0406	-0.0922	-2.6083	-7.1663
6	9.45	-778.2	88.4	-0.0406	-0.0922	-2.5803	-7.0893
7	9.55	-856.7	-12.4	-0.0488	-0.0594	-2.5523	-7.0123
8	10.05	-908.5	-143.8	-0.0441	-0.0784	-2.3504	-6.8584

\# DATA: 02/28/93
\# Data Name: A4-B

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	10.55	-500.2	1015.1	-0.0690	-0.0019	-0.7785	-5.4812
2	11.05	-547.4	941.6	-0.0690	-0.0019	-0.7434	-5.2341
3	11.15	-605.3	919.9	0.0684	-0.2380	-0.9129	-5.0483
4	11.25	-640.2	847.7	-0.0258	-0.0519	-1.0694	-4.8573
5	11.35	-685.6	825.8	-0.2037	0.2861	-1.2129	-4.6620
6	11.45	-745.4	782.4	0.1637	-0.3472	-1.3432	-4.4630
7	11.55	-826.8	796.5	-0.0301	-0.0192	-1.4602	-4.2610
8	12.15	-924.5	718.0	-0.0426	-0.0190	-1.5341	-3.9964
9	12.25	-933.7	683.3	-0.0426	-0.0190	-1.5447	-3.8882
10	12.35	-957.7	612.3	-0.0463	-0.0141	-1.5530	-3.7804
11	12.45	-955.9	582.3	-0.0379	-0.0043	-1.5591	-3.6729
12	12.55	-992.6	530.4	-0.0457	-0.0072	-1.5628	-3.5658
13	13.05	-1035.2	462.9	-0.0396	-0.0095	-1.4891	-3.4800
14	13.15	-1102.5	513.6	-0.0340	-0.0013	-1.3436	-3.4109
15	13.25	-1053.1	340.2	-0.0005	0.0013	-1.2034	-3.3364
16	13.35	-1103.4	308.9	0.0002	-0.0006	-1.0686	-3.2567
17	14.05	-1143.3	204.2	-0.0133	0.0040	-1.9943	-2.2149
18	14.15	-1123.7	181.0	-0.0133	0.0040	-2.6563	0.3733

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\# DATA: 03/06/93
\# Data Name: A5-O

# No.	time	X	Y	Current(x)	Current y)	Wind(x)	Wind(y)
1	9.55	615.9	-816.7	-0.1023	0.0017	-2.4645	-4.2686
2	10.05	525.7	-866.2	-0.1023	0.0017	-2.3262	-4.1116
3	10.15	428.5	-921.7	-0.1118	-0.0593	-1.9749	-3.9610
4	10.25	337.8	-985.3	-0.0650	-0.0266	-1.6460	-3.7856
5	10.35	257.4	-1076.4	-0.0505	-0.0893	-1.3413	-3.5874
6	10.45	200.2	-1192.9	0.0215	-0.1817	-1.0620	-3.3684
7	10.55	164.8	-1355.2	0.0215	-0.1817	-0.8097	-3.1308
8	11.25	221.5	-1901.5	0.1432	-0.3388	-0.8766	-3.0740

DATA: 03/06/93
Data Name: A6-O

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	12.20	1080.5	-292.6	0.2840	-0.6066	-1.5734	-2.6186
2	12.30	1206.7	-655.1	0.2840	-0.6066	-1.7285	-2.3360
3	12.40	1316.2	-925.7	0.2078	-0.3949	-1.8447	-2.0488
4	12.50	1414.2	-1182.3	0.2386	-0.4039	-1.9228	-1.7619
5	13.00	1428.0	-1362.8	0.1261	-0.2851	-1.9638	-1.4798
6	13.10	1461.6	-1522.8	0.1191	-0.1873	-1.9435	-1.5184
7	13.20	1488.5	-1621.6	0.1024	-0.1382	-1.9225	-1.5568
8	13.30	1512.0	-1762.9	0.0951	-0.1313	-1.9007	-1.5949
9	13.40	1522.2	-1877.2	0.1557	-0.1918	-1.8782	-1.6327
10	13.50	1490.3	-1965.9	0.0967	-0.1360	-1.8550	-1.6702
11	14.20	1542.8	-2297.2	0.0575	-0.1082	-2.1777	-1.1417
12	14.40	1581.5	-2537.2	0.0575	-0.1082	-2.3585	-0.5157

DATA: 03/07/93
Data Name: A7-O

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	9.05	721.7	-517.5	-0.2429	0.3946	-4.8634	-3.5551
2	9.15	524.7	-339.7	-0.2429	0.3946	-4.7528	-3.5169
3	9.25	257.3	-88.4	-0.2288	0.3053	-4.6428	-3.4775

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\# DATA: 03/07/93
\# Data Name: A8-O

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	9.50	1392.0	-1063.8	-0.3486	0.0396	-4.3706	-3.3739
2	10.00	1135.3	-1104.3	-0.3486	0.0396	-4.2628	-3.3305
3	10.10	910.2	-1012.7	-0.3528	0.2008	-4.4650	-2.9741
4	10.20	763.7	-987.9	-0.1899	0.0713	-4.6380	-2.6063
5	10.30	617.9	-956.9	-0.1980	0.1228	-4.7812	-2.2295
6	10.40	456.1	-917.7	-0.1799	0.0805	-4.8941	-1.8461
7	10.50	306.8	-885.5	-0.1799	0.0805	-4.9767	-1.4584
8	11.00	189.4	-897.5	-0.5233	-0.3122	-5.0290	-1.0689
9	11.10	72.2	-894.0	-0.3942	-0.3282	-5.0102	-1.0497
10	11.20	-19.2	-916.0	0.1789	0.3718	-4.9913	-1.0306
11	11.30	-131.8	-970.2	-0.0965	-0.0473	-4.9724	-1.0116
12	11.40	-195.4	-1026.7	-0.0408	-0.1016	-4.9534	-0.9928
13	11.50	-278.7	-1157.6	-0.0397	-0.2354	-4.9343	-0.9740
14	12.00	-490.5	-1491.6	-0.0335	-0.5081	-4.9152	-0.9554
15	12.10	-418.5	-1503.3	0.0351	0.0358	-4.6994	-0.9704
16	12.20	-436.9	-1672.4	0.0314	-0.3639	-4.4840	-0.9804
17	12.30	-440.7	-1852.4	0.0056	-0.5780	-4.2690	-0.9856
18	13.00	-542.7	-2861.5	0.0056	-0.5780	-3.6274	-0.9720
19	13.20	-515.0	-3371.3	0.1409	-0.2676	-3.1429	-1.2911
20	13.30	-482.9	-3619.3	0.1207	-0.4324	-2.8931	-1.4111
21	13.40	-513.9	-4214.9	0.0864	-0.4231	-2.6416	-1.5047

DATA: 02/27/93
Data Name: B1-B

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	9.55	-93.9	1389.1	0.0421	-0.3172	0.0918	-7.8865
2	10.03	-97.6	1401.0	0.0421	-0.3172	0.0339	-7.7789
3	10.19	-64.1	932.0	0.0110	-0.0221	0.2018	-7.2994
4	10.34	-61.2	847.5	0.0110	-0.0221	0.3389	-6.8467
5	10.50	-69.2	612.4	0.0106	-0.0681	0.4634	-6.3613
6	10.57	-67.9	524.9	0.0144	-0.0783	0.5109	-6.1484
7	11.10	-48.3	367.0	0.0487	-0.0982	0.6600	-5.6468
8	11.19	-34.6	275.8	0.0487	-0.0982	0.7571	-5.2758
9	11.26	-36.1	276.3	0.0265	-0.0237	0.8195	-4.9865

DATA: 02/27/93
Data Name: B2-B

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	12.24	200.8	1125.7	-0.0457	-0.0873	1.3112	-2.8120
2	12.34	227.1	1215.5	-0.0457	-0.0873	1.3886	-2.4880
3	12.44	234.2	1197.6	-0.0428	-0.0357	1.4265	-2.1689
4	13.02	289.4	1219.3	-0.1898	-0.9510	1.4016	-1.7164
5	13.12	288.1	1026.0	-0.1898	-0.9510	1.3571	-1.9096
6	13.22	300.4	901.4	-0.0626	-0.1592	1.2927	-2.1039
7	13.32	286.6	764.6	0.0342	0.2504	1.2081	-2.2978

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\# DATA: 02/27/93
\# Data Name: B3-B

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	14.30	-123.6	1199.1	0.0189	-0.1698	2.4139	-2.8768
2	14.40	-53.6	769.9	0.0189	-0.1698	2.9744	-2.7097
3	14.50	-43.2	631.0	0.0217	-0.1530	3.5300	-2.4412
4	15.00	-36.9	537.0	-0.0386	0.0145	4.0631	-2.0702

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DATA: 02/28/93
Data Name: B4-B

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	8.55	95.1	1112.5	0.0091	0.4433	-2.6937	-7.4009
2	9.05	10.8	929.7	0.0091	0.4433	-2.6924	-7.3974
3	9.15	-76.6	785.9	-0.0016	-0.0964	-2.6644	-7.3204
4	9.25	-160.8	651.4	-0.0010	-0.0682	-2.6364	-7.2434
5	9.37	-230.0	444.0	-0.2184	0.0374	-2.6027	-7.1509
6	9.47	-311.3	377.4	-0.2184	0.0374	-2.5747	-7.0739
7	9.57	-369.6	223.4	-0.0407	-0.0802	-2.5467	-6.9969
8	10.07	-440.3	95.1	-0.0311	-0.0527	-2.2767	-6.8110

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DATA: 02/28/93
Data Name: B5-B

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	10.40	-117.6	901.1	-0.0132	-0.0658	-1.1890	-5.9324
2	11.00	-202.1	668.0	-0.0132	-0.0658	-0.6538	-5.3249
3	11.10	-240.4	561.8	-0.0033	-0.0610	-0.8297	-5.1418
4	11.25	-283.1	351.3	0.0174	-0.0324	-1.0694	-4.8573
5	11.35	-302.3	277.8	0.0174	-0.0324	-1.2129	-4.6620
6	11.45	-317.6	184.2	0.0120	-0.0241	-1.3432	-4.4630
7	11.55	-341.2	83.2	0.0060	-0.0355	-1.4602	-4.2610
8	12.08	-378.5	-41.1	-0.0074	-0.0538	-1.5252	-4.0722
9	12.18	-413.1	-149.3	-0.0074	-0.0538	-1.5375	-3.9639

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DATA: 02/28/93
Data Name: B6-B

#	No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
	1	12.42	-303.8	1103.0	-0.0475	0.0022	-1.5575	-3.7051
	2	12.52	-374.1	1063.4	-0.0475	0.0022	-1.5619	-3.5979
	3	13.02	-438.6	1011.1	-0.0205	-0.0262	-1.5338	-3.4996
	4	13.12	-516.1	966.6	-0.0647	0.0130	-1.3867	-3.4322
	5	13.22	-568.6	884.5	-0.0896	0.0824	-1.2449	-3.3593
	6	13.32	-664.3	814.0	-0.0215	-0.1079	-1.1085	-3.2811
	7	13.42	-749.6	752.2	-0.0444	-0.0241	-0.9777	-3.1980
	8	13.56	-847.4	703.1	0.1887	-0.1876	-0.8044	-3.0736
	9	14.06	-904.8	667.1	0.1887	-0.1876	-2.1789	-1.9896
	10	14.16	-956.1	596.3	-0.0368	-0.0074	-2.5782	0.6237
	11	14.25	-1015.2	543.2	-0.0573	0.0007	-0.8207	2.2069

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DATA: 03/06/93
Data Name: B7-O

#	No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
	1	9.40	-720.7	-728.4	-0.1086	0.1279	-2.3138	-4.5411
	2	9.50	-803.5	-734.7	-0.1086	0.1279	-2.4167	-4.3598
	3	10.05	-978.3	-822.0	0.0550	0.1174	-2.3262	-4.1116
	4	10.15	-1037.6	-854.9	0.0550	0.1174	-1.9749	-3.9610
	5	10.25	-1112.4	-907.4	-0.1118	-0.0301	-1.6460	-3.7856
	6	10.35	-1181.7	-957.7	-0.0151	-0.0150	-1.3413	-3.5874

\# DATA: 03/06/93
\# Data Name: B8-O

#	No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
	1	10.55	-250.5	-1228.3	0.0316	-0.1055	-0.8097	-3.1308
	2	11.05	-247.4	-1281.1	0.0316	-0.1055	-0.7297	-3.0202
	3	11.15	-245.7	-1490.2	0.0731	-0.2663	-0.8025	-3.0480
	4	11.25	-242.5	-1701.5	0.0740	-0.4017	-0.8766	-3.0740
	5	11.35	-241.8	-1971.0	0.2146	-0.4942	-0.9522	-3.0982

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\# DATA: 03/06/93
\# Data Name: B9-O

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	12.42	69.3	-720.9	0.1595	-0.9841	-1.8634	-1.9912
2	12.52	82.1	-1111.7	0.1595	-0.9841	-1.9339	-1.7049
3	13.02	86.3	-1566.2	0.0589	-0.2112	-1.9598	-1.4875
4	13.12	86.2	-1812.9	0.0569	-0.3426	-1.9394	-1.5261
5	13.32	107.6	-2250.0	0.0694	-0.2992	-1.8963	-1.6025
6	13.42	184.7	-2648.6	0.0694	-0.2992	-1.8736	-1.6403
7	13.52	211.3	-2784.8	0.0556	-0.1450	-1.8503	-1.6777
8	14.02	227.5	-3209.0	0.1427	-0.4307	-1.8727	-1.6549

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\# DATA: 03/07/93
\# Data Name: B10-O

# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	9.35	-1142.7	-1363.7	-0.2729	-0.0498	-4.5334	-3.4369
2	9.45	-1278.6	-1267.0	-0.2729	-0.0498	-4.4247	-3.3952
3	9.55	-1470.2	-1063.1	-0.1211	0.7708	-4.3166	-3.3523
4	10.09	-1561.5	-864.0	0.5392	0.5749	-4.4461	-3.0102
5	10.19	-1570.4	-690.6	0.5392	0.5749	-4.6220	-2.6435

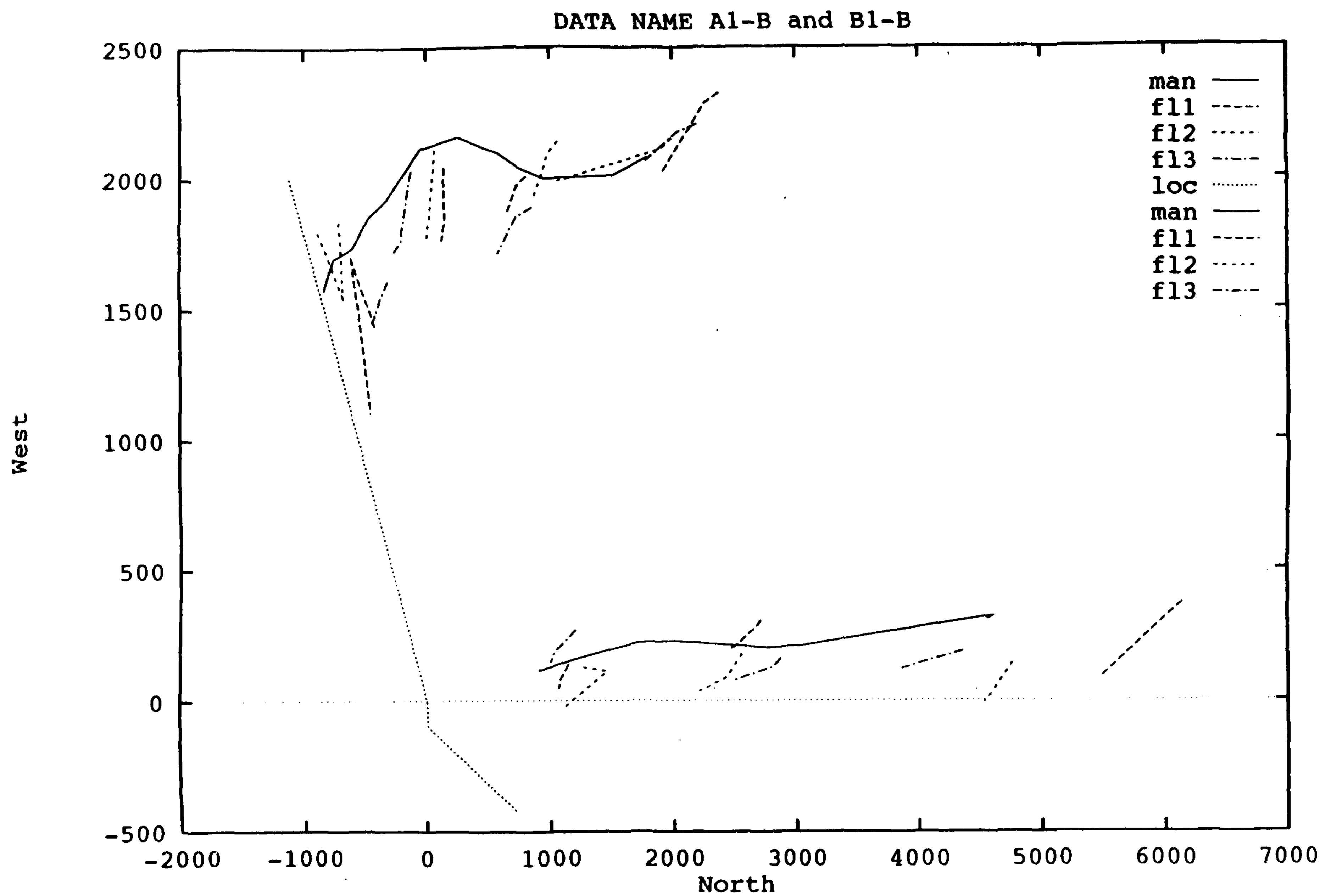
DATA: 03/07/93
Data Name: B11-O

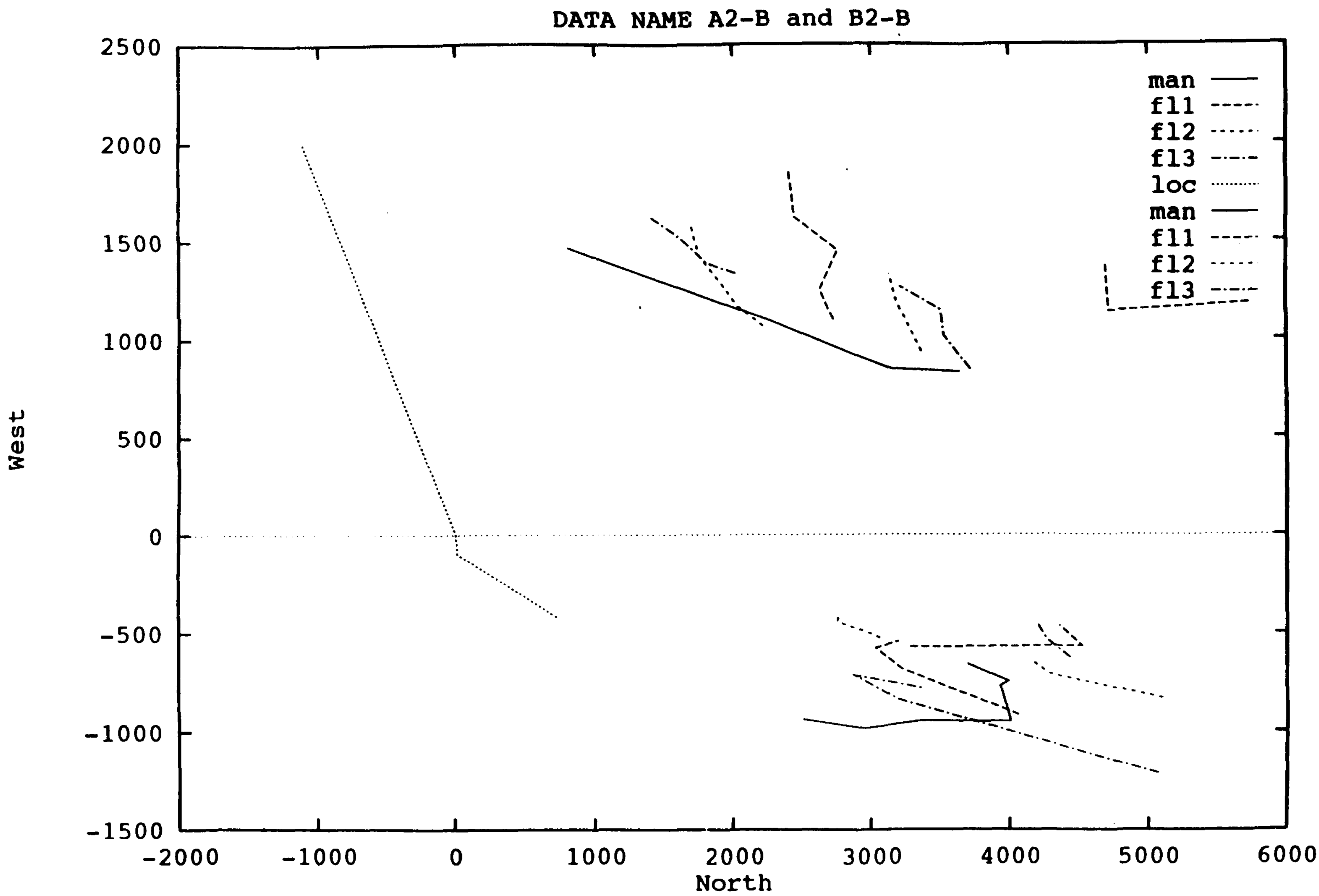
# No.	time	X	Y	Current(x)	Current(y)	Wind(x)	Wind(y)
1	10.34	115.4	-996.7	-0.1827	0.1398	-4.8300	-2.0768
2	10.44	-27.7	-954.1	-0.1827	0.1398	-4.9308	-1.6914
3	10.54	-185.0	-911.0	-0.1523	0.1069	-5.0012	-1.3027
4	11.04	-316.8	-865.3	-0.1289	0.0863	-5.0214	-1.0612
5	11.18	-473.4	-815.7	-0.1180	0.0100	-4.9951	-1.0344
6	11.28	-635.5	-819.5	-0.1180	0.0100	-4.9762	-1.0154
7	11.38	-771.5	-876.8	-0.0828	-0.0706	-4.9572	-0.9965
8	11.48	-854.2	-940.0	-0.0342	-0.0742	-4.9381	-0.9778
9	12.01	-951.3	-1063.5	-0.0128	-0.3975	-4.8936	-0.9571
10	12.11	-1028.6	-1275.7	-0.0128	-0.3975	-4.6779	-0.9716
11	12.21	-1030.7	-1014.2	0.0187	-0.3853	-4.4625	-0.9811
12	12.31	-1094.3	-1766.4	0.0455	-0.4711	-4.2475	-0.9858
13	12.43	-1147.7	-2055.4	-0.0218	-0.4437	-3.9903	-0.9850
14	12.53	-1213.0	-2367.5	-0.0218	-0.4437	-3.7766	-0.9790
15	13.03	-1327.7	-2720.7	-0.1412	-0.7951	-3.5566	-1.0265

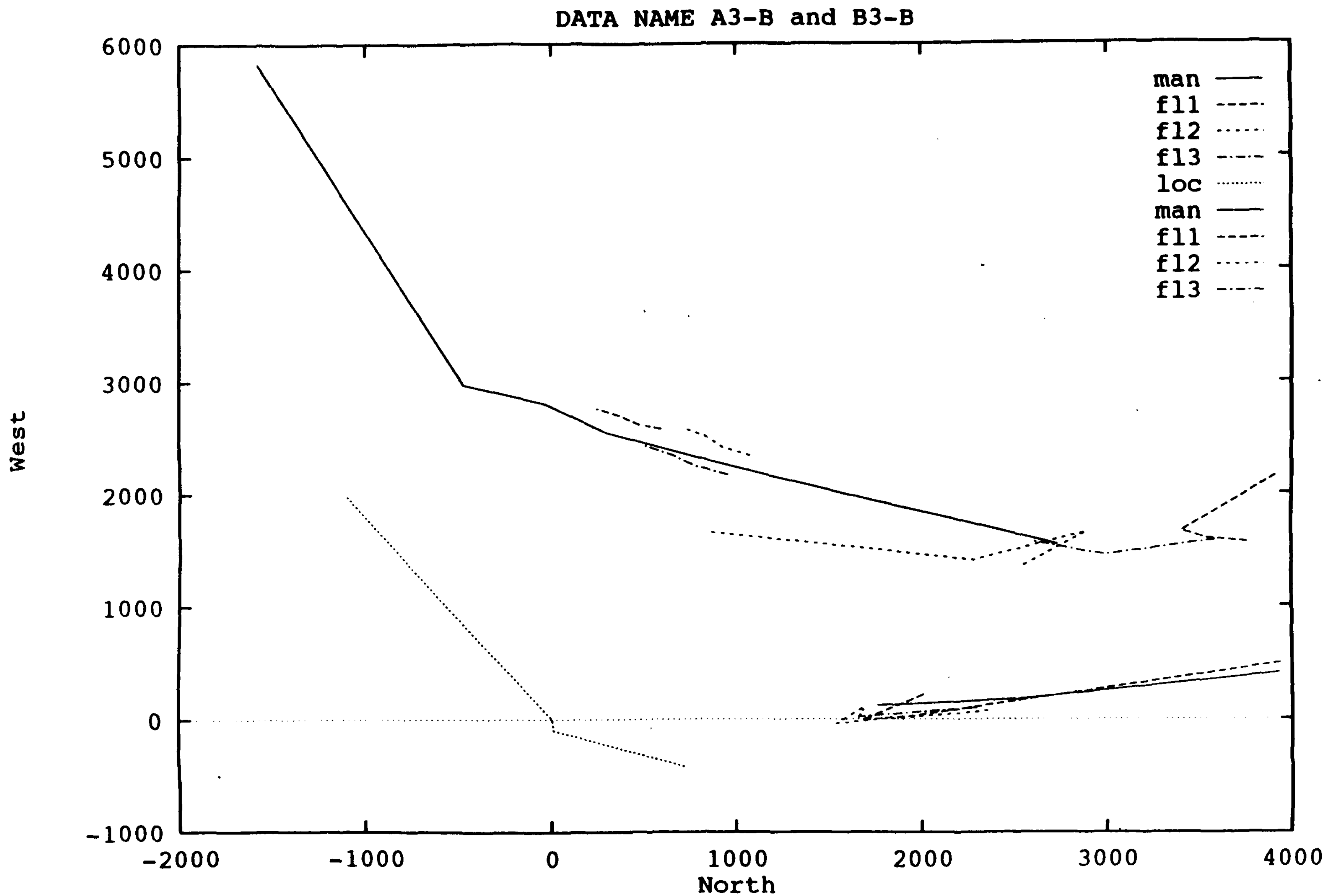
APPENDIX II

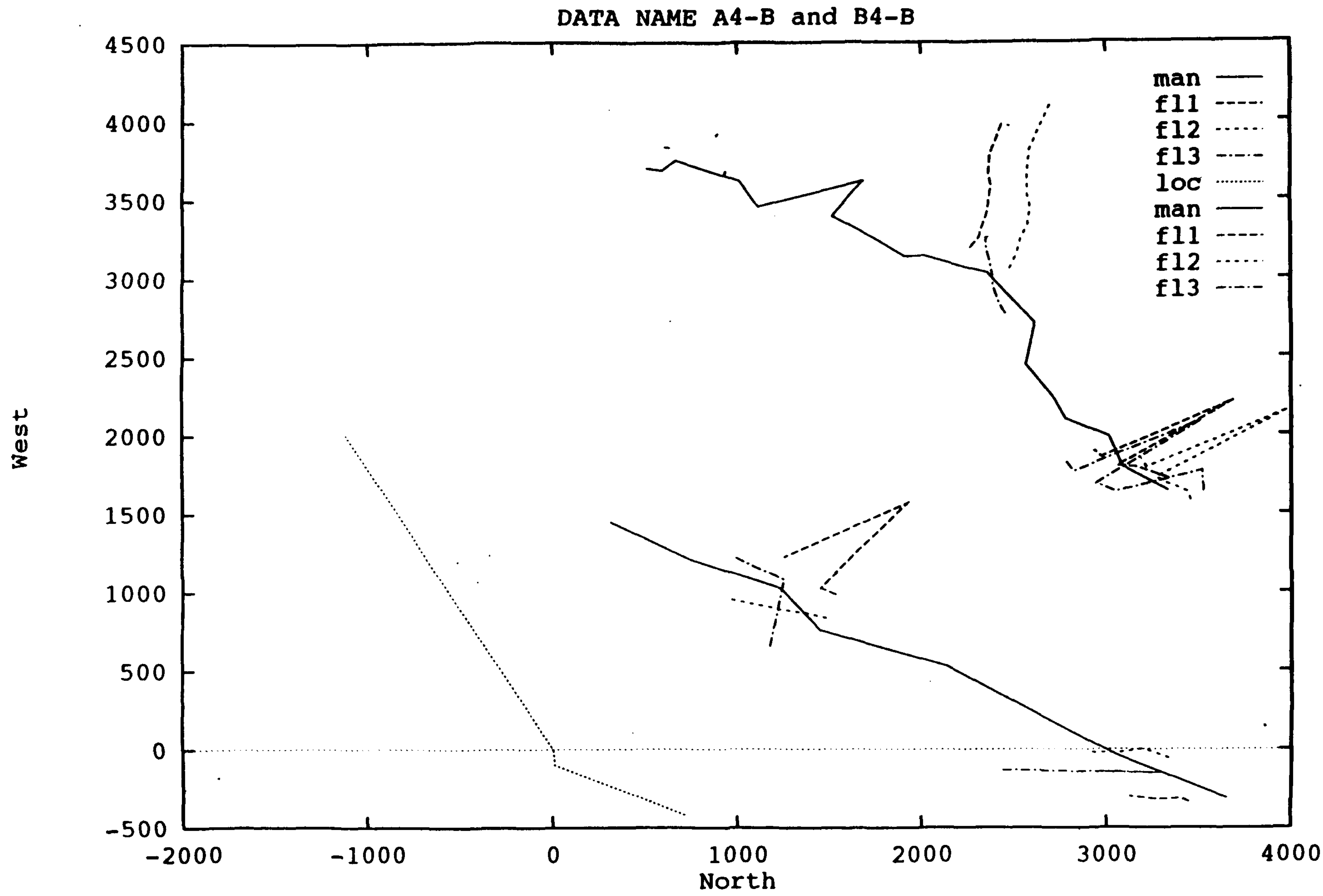
FIELD DATA PLOT

(Trajectories of Search Target and Drifters)

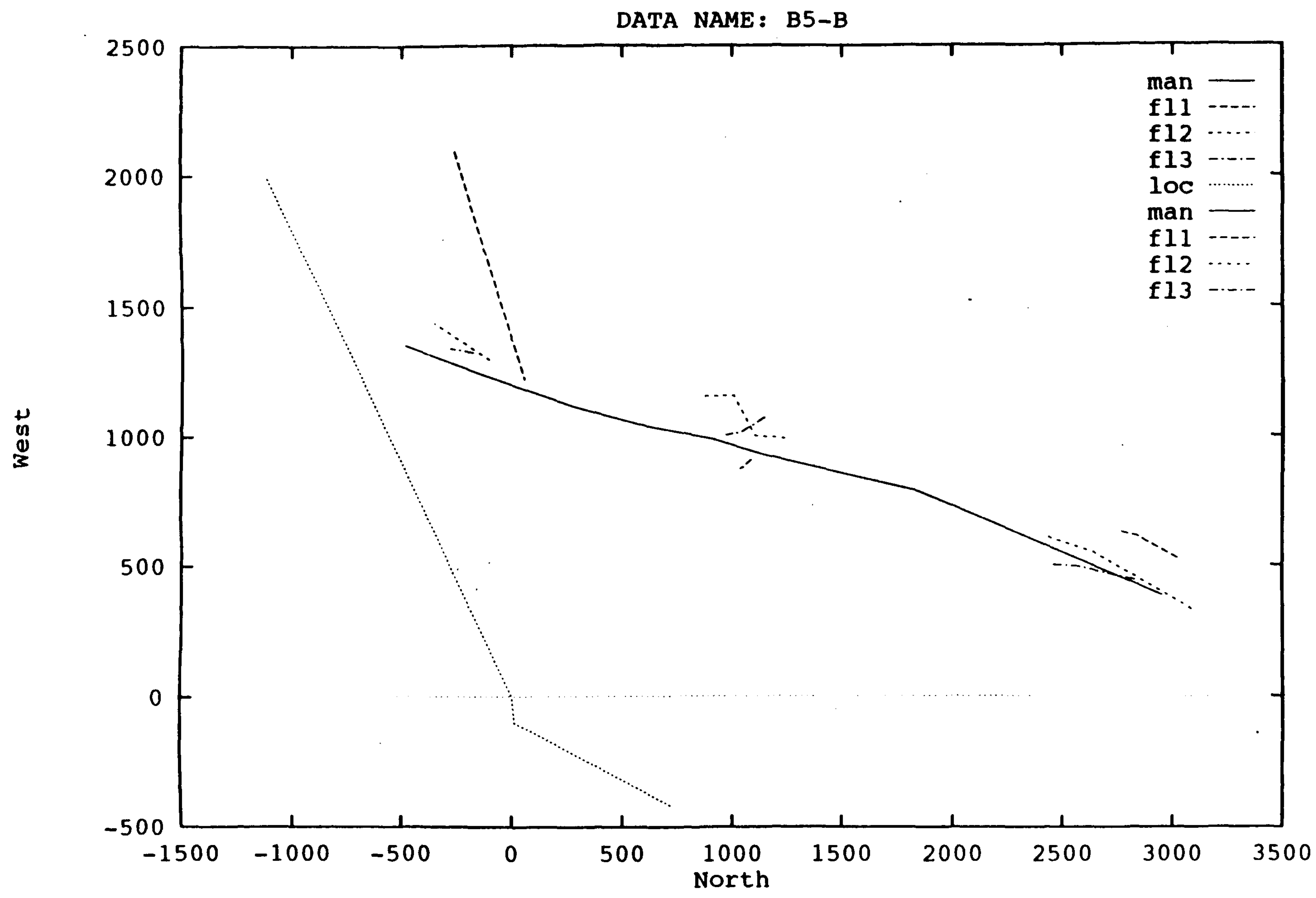

DATA NAME A1-B and B1-B
West
North
man
f11
f12
f13
loc
man
f11
f12
f13
2500
2000
1500
1000
500
0
-500
-2000
-1000
0
1000
2000
3000
4000
5000
6000
7000


DATA NAME A2-B and B2-B
man
f11
f12
f13
loc
man
f11
f12
f13
West
North
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-1000
0
1000
2000
3000
4000
5000
6000

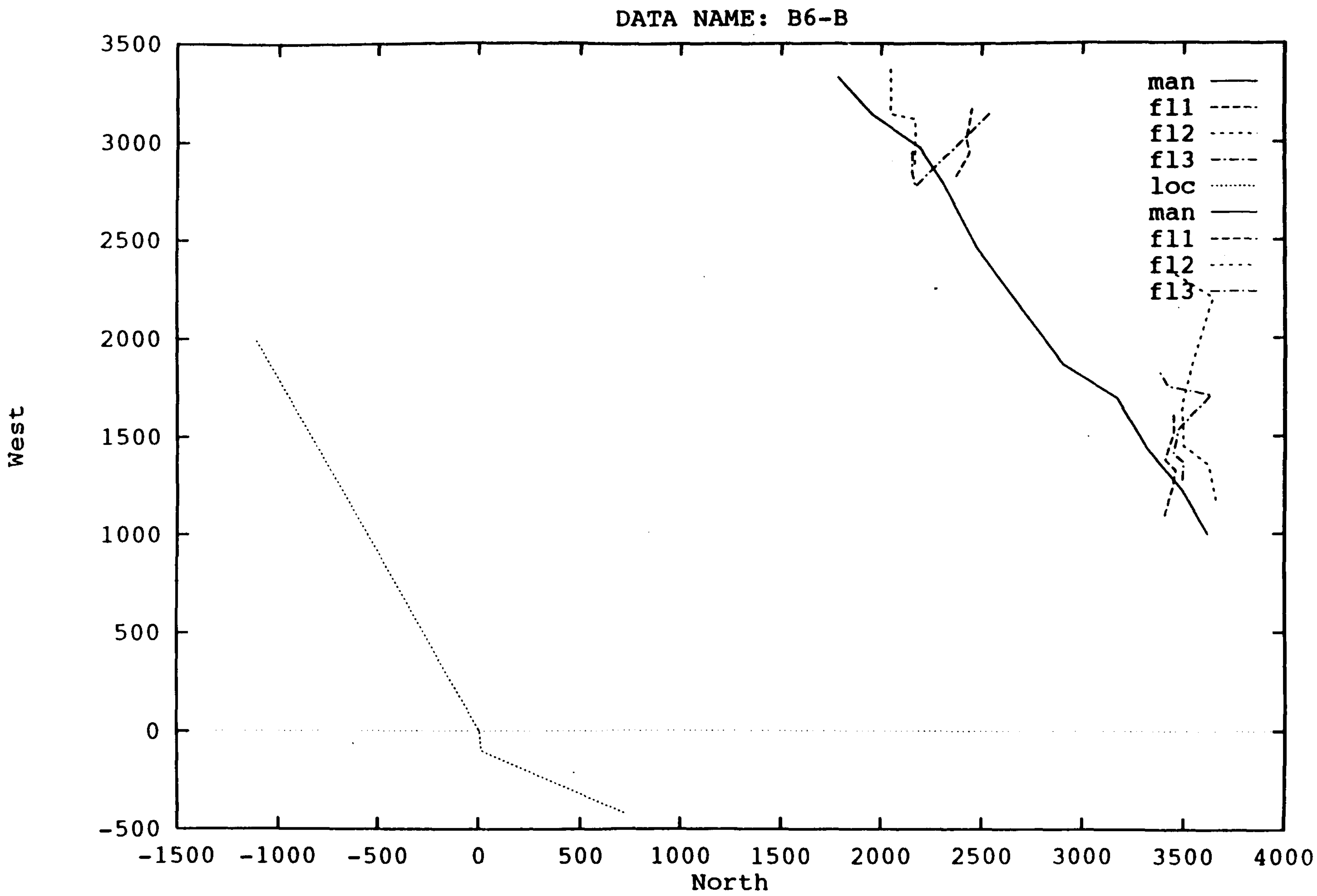

DATA NAME A3-B and B3-B
West
North
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-1000
0
1000
2000
3000
4000
man
f11
f12
f13
loc
man
f11
f12
f13

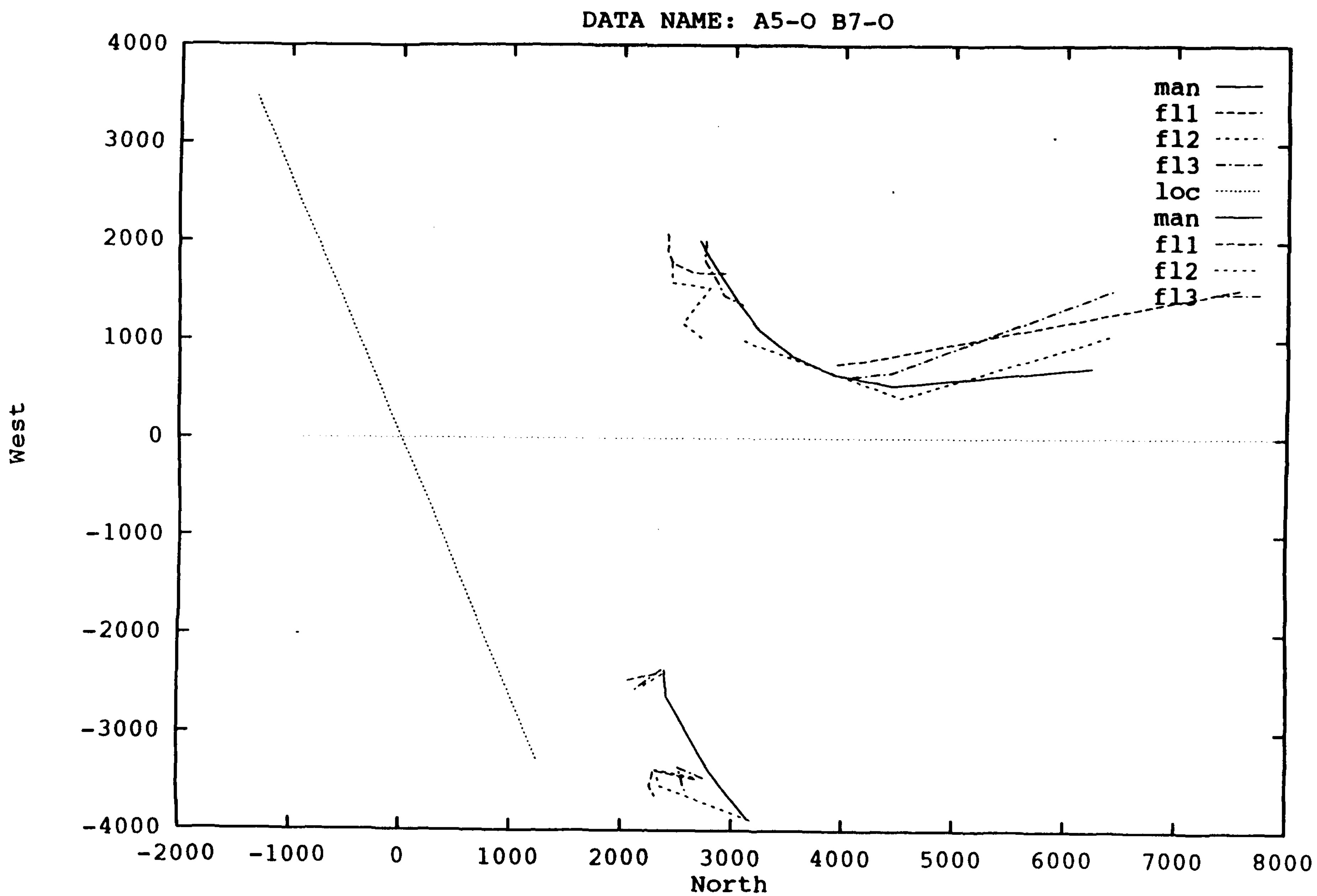


DATA NAME A4-B and B4-B
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
-2000
-1000
0
1000
2000
3000
4000
North
West
man
f11
f12
f13
loc
man
f11
f12
f13



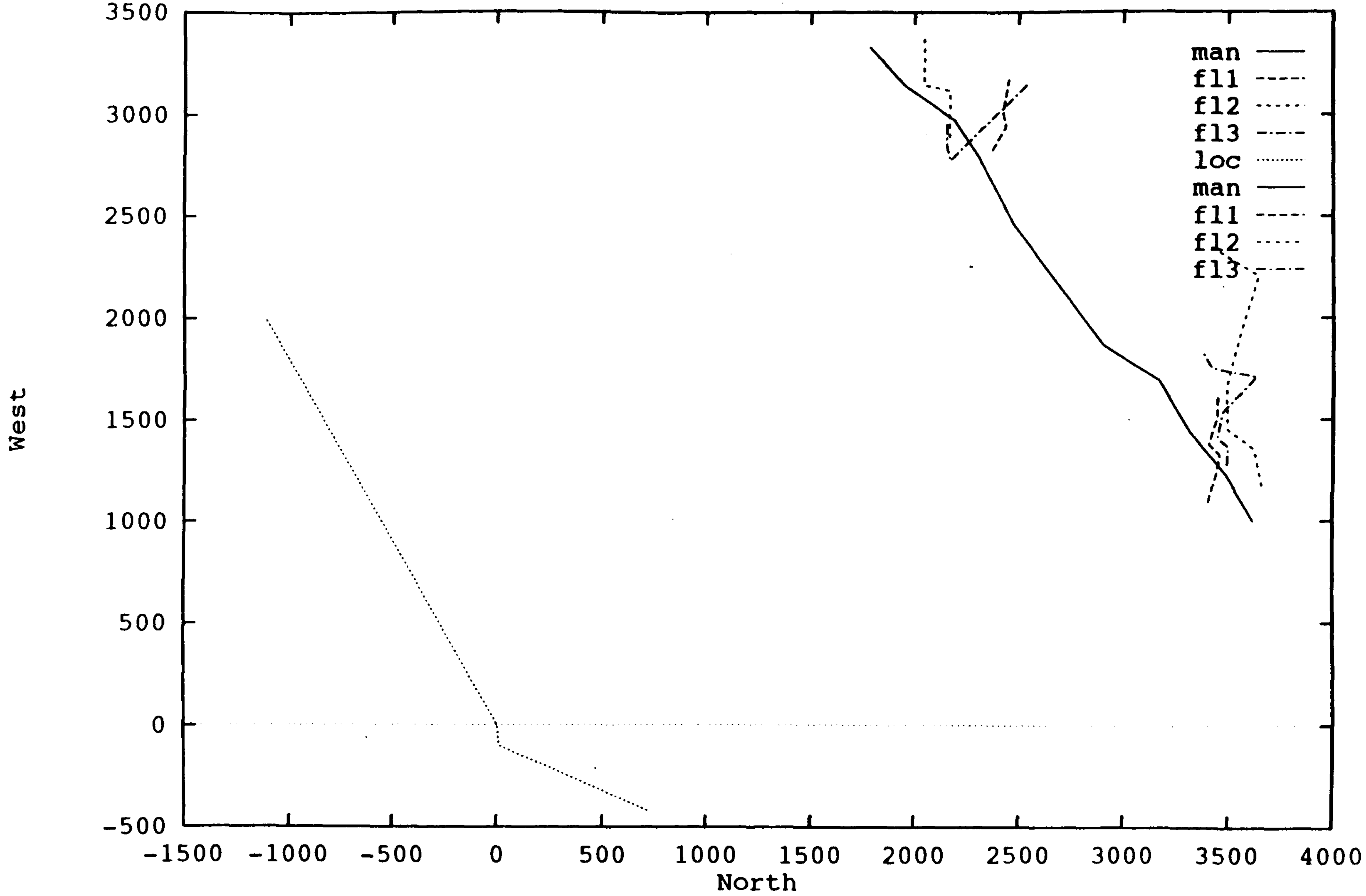
DATA NAME: B5-B
West
North
2500
2000
1500
1000
500
0
-500
-1500
-1000
-500
0
500
1000
1500
2000
2500
3000
3500
man
f11
f12
f13
loc
man
f11
f12
f13

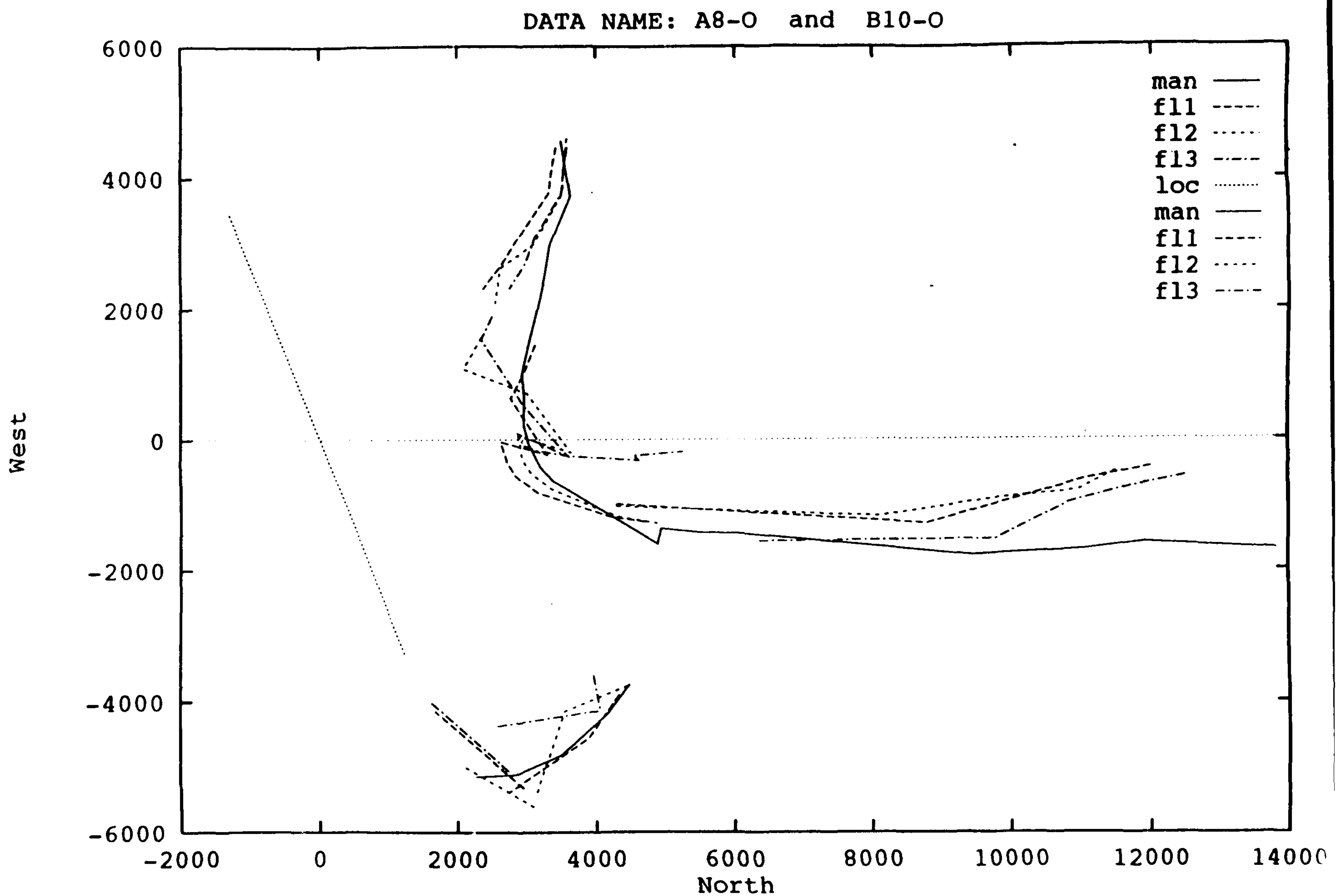

DATA NAME: B6-B
man
f11
f12
f13
loc
man
f11
f12
f13
West
North
3500
3000
2500
2000
1500
1000
500
0
-500
-1500
-1000
-500
0
500
1000
1500
2000
2500
3000
3500
4000



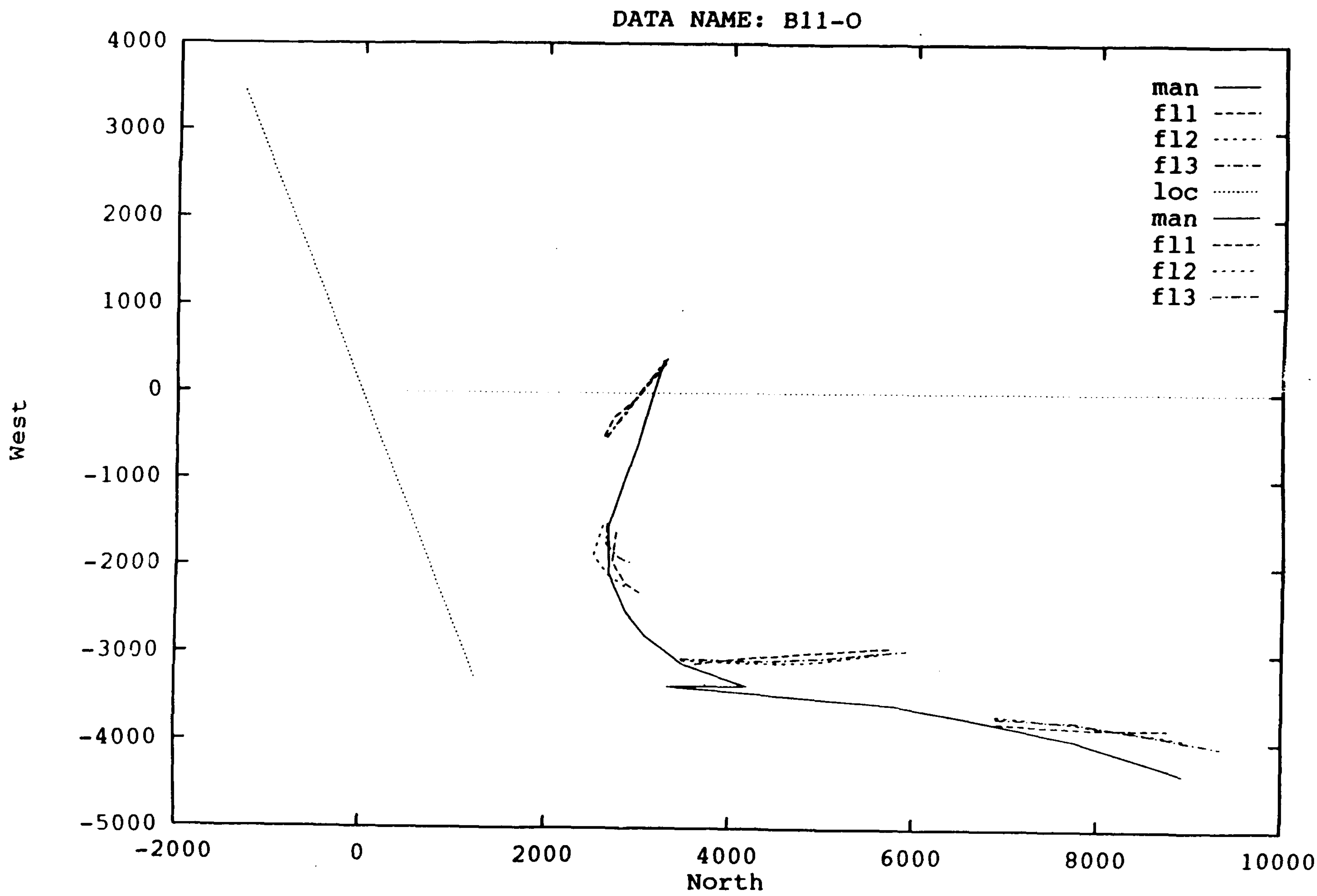
DATA NAME: A5-O B7-O
man
f11
f12
f13
loc
man
f11
f12
f13
West
North
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-2000
-1000
0
1000
2000
3000
4000
5000
6000
7000
8000

DATA NAME: B6-B





DATA NAME: A8-O and B10-O
6000
4000
2000
0
-2000
-4000
-6000
West
-2000
0
2000
4000
6000
8000
10000
12000
14000
North
man
f11
f12
f13
loc
man
f11
f12
f13


DATA NAME: B11-O
man
f11
f12
f13
loc
man
f11
f12
f13
West
North
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-2000
0
2000
4000
6000
8000
10000